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(71) Applicant: FLOOR SAFETY ENGINEERING, INC. [US/US]; P.O. Box Q, Nashua, NH 03061 (US).

(72) Inventor: BANUS, Christopher, T.; 41 Manchester Street, Nashua, NH 03060 (US).

(74) Agents: CELLA, Charles, H. et al.; Foley, Hoag & Eliot LLP, One Post Office Square, Boston, MA 02109 (US).

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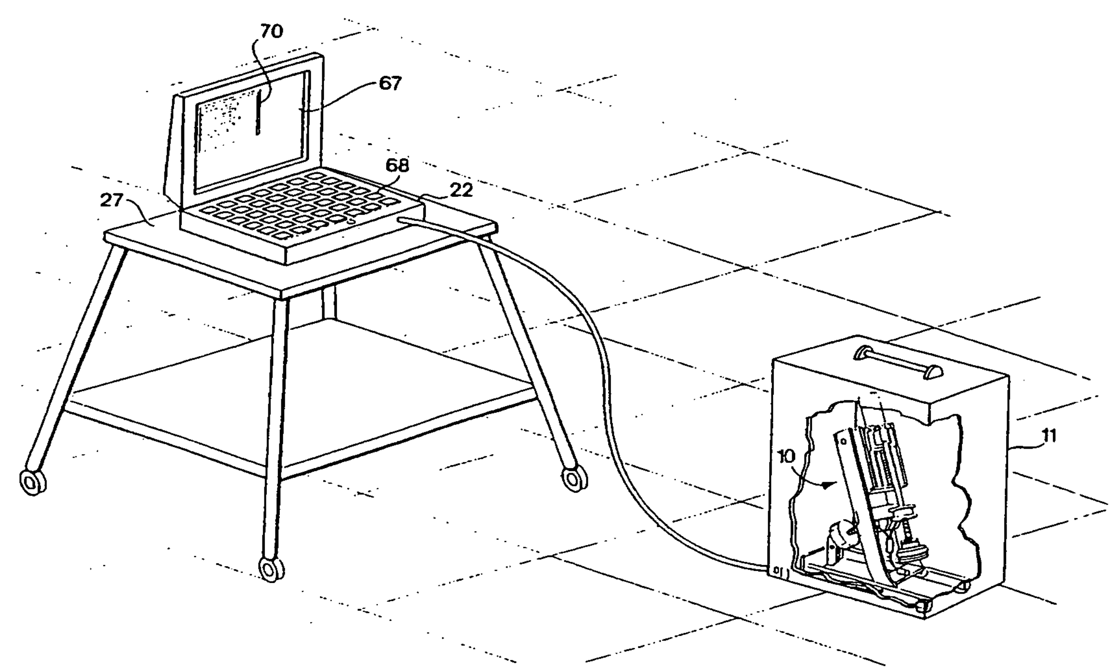

(57) Abstract

A test assembly (10) designed for measuring a coefficient of friction is housed in a cover (11) and is electrically connected to a portable central processing unit (22) supported on a wheeled cabinet or computer stand (27). The portable central processing unit (22) includes a conventional user interface (67) including a keypad (68) and a graphical display (70).

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DEVICE FOR MEASURING AND MAINTAINING FLOOR SAFETY

Technical Field

This application relates to the field of measurement of slip resistance and more particularly to an improved device and method for obtaining precise measurements of coefficients of friction of floor surfaces.

Background of The Invention

Measurements of the coefficients of friction between surfaces are used in a wide variety of applications to predict the behavior of physical interactions between two or more surfaces in physical systems. Such measurements permit, for example, the measurement of the coefficients of friction between discs in disc brakes or clutch mechanisms for automobiles and coefficients of friction of ball bearings in a variety of applications. Industry standards have been established for minimum static coefficient of friction that is permitted in certain surfaces, such as commercial floors and bathtubs. For testing purposes, a need has arisen to have a device that can be transported to different sites in order to reliably test floor surfaces under field conditions.

Coefficients of friction measured by conventional devices include one or more of the following: (1) the static coefficient of friction, which is the calculated by dividing the horizontal force required to initiate movement of a weighted object over a surface divided by the vertical force of the object on the surface, (2) the dynamic coefficient of friction, which is the horizontal force required to continue movement of a weighted object over a surface divided by the vertical force of the object on the

surface, or (3) a different set of coefficients of friction which will be referred to by the coined phrase "stopping coefficient of friction™." The stopping coefficients of friction may be further broken down into two other coefficients of friction, the first of which may be referred to by the coined term "air-to-stop™" stopping coefficient of friction, which is the ratio of horizontal to vertical force required in order to stop a moving test object more or less instantaneously upon contacting a test surface and the second of which may be referred to by the coined term "dynamic-to-stop™" stopping coefficient of friction, which is the ratio of horizontal to vertical force required in order to stop a test object more or less instantaneously as it slides across a test surface. Certain machines described below measure the air-to-stop stopping coefficient of friction, rather than the static coefficient of friction required by current industry standards. No party appears to have developed a device that measures the dynamic-to-stop stopping coefficient of friction.

Most conventional devices for measurement of one or more of the coefficients of friction manipulate test surfaces of varying materials to interact with each other and permit measurement of various characteristics of the interaction. Over time, many devices have been developed for testing slip resistance.

Examples of conventional devices that measure coefficients of friction include U.S. Patent No. 5,490,410, to Markström ("Markström"), which provides a process for measuring static and dynamic friction of sheet-shaped materials. Layer materials, such as paper, are disposed on a surface and counter-surface, which are pressed

together by plates with a normal force. A screw-nut device, driven by a motor, moves the plates relative to each other, and a force measuring cell, such as a wire strain gauge, measures and outputs the force required to initiate or to continue movement between the plates, permitting calculation of the static and dynamic coefficients of friction between the measured surfaces.

U.S. Patent No. 5,542,281, to Lee et al. ("Lee") provides a method and apparatus for measuring the coefficient of friction of the surface of a cylindrical object. A motor, controlled by a CPU, rotates a cylindrical test surface. A flexible material, such as tape or wire, is disposed in contact with the cylindrical surface and also connected to a tension meter, so that the tension in the flexible material may be measured upon rotation of the cylinder by the motor. The tension measurement permits calculation of the coefficient of friction between the cylindrical surface and the flexible material.

U.S. Patent No. 3,717,025, to Kronenberg et al. ("Kronenberg") provides an apparatus and method for determining static and dynamic friction of the working surface of a friction disc, such as the discs used in clutches and disc brakes. A disc holding assembly includes a diaphragm-type, roto-chamber air cylinder for precisely positioning the disc against a rotating surface. The rotation of the surface is motor controlled. The disc holding assembly is connected to a strain-gauged torque link. The torque measurement indicates the coefficient of friction between the friction disc and the rotating surface. Kronenberg also provides a mechanism for submerging the test

surface in oil, to permit testing of the disc under realistic conditions.

U.S. Patent No. 5,281,535, to Wei et al. ("Wei") provides a method and apparatus for testing coefficients of friction in a controlled environment. Wei provides a closed housing into which testing fluids may be introduced or removed. In the housing, a contact element is driven by a drive mechanism, such as a carriage drive, to contact a sample material, which is disposed on a sample station, which may be a rotating turntable. Thomson rods with internal, CPU controlled motor-driven screws are used to initiate contact between the sample station and the contact element. A strain gauge may be attached to the support arm for the turntable to measure strain on the contact element during testing. The device permits a determination of the amount of wear caused by contact between the test surface and the contact element under controlled conditions of temperature and pressure.

U.S. Patent No. 4,569,222, to Arnold et al. ("Arnold") provides a rolling caster floor tester. A sample of floor material is attached to a moving plate and moved under a fixed caster wheel. The plate is moved by a variable-speed, motor-driven screw drive gear to permit variable orientation, pressure and force between the caster and the floor material. A recording instrument provides a record of the load readings on the caster under different contact conditions. A pneumatic cylinder acting through a piston furnishes the load weight on the caster. The load readings provide detailed information on the reaction of sample floor materials to particular actions of casters on them.

U.S. Patent No. 4,672,838, to Reh ("Reh") provides a bearing friction tester. A test bearing is housed within a gimbal support assembly that hangs from a horizontal arm and that is attached above a swinging pendulum mechanism. The angular distance traveled and rate of decay of the pendulum are measured by a test instrument, permitting a calculation of the energy lost to frictional forces between the gimbal support assembly and the test bearing.

U.S. Patent No. 4,173,885, to Matlock ("Matlock") provides a surface assembly for calibrating a variable speed friction tester. The friction tester described in Matlock is a pendulum-swing type tester that includes a tire surface disposed on a pendulum that impacts a test surface at the bottom of the pendulum path. Measurement of the angle of travel of the pendulum after contact with the test surface permits a measurement of the coefficient of friction between the tire and the surface.

Also well-known in the prior art are force plates. Force plates are large plates, typically several square feet in area, mounted on load cells and connected to a computer so as to permit graphical display of vertical and horizontal forces exerted on the force plate as a person walks across the force plate. Force plates do not measure the slip characteristics of a walking surface, but provide a dynamic measurement of the various forces involved in walking at different points in the human stride. Force plates are useful in projecting from laboratory conditions some of the forces of the human gait in field conditions. However, force plates are too unwieldy to use in the field, and force plate results only yield a rough approximation of the effects of the human gait under

field conditions, without actually measuring coefficients of friction. Force plates do provide useful insight into the types of forces involved in walking.

All of the devices heretofore described are quite specialized in function and are limited by the fact that they provide for interaction of controlled test materials under a limited set of controlled conditions. A particular drawback shared by these devices is that the devices cannot be effectively used to measure coefficients of friction of actual working parts or materials in the field. In some areas, where field conditions are quite similar to laboratory conditions and are relatively controlled, such as the environment of a ball bearing or disc brake, the conventional devices may be effective; however, where field conditions are highly variable, such as on floor surfaces that are repeatedly subjected to a wide variety of environmental conditions, wear and contaminants, controlled laboratory results do not accurately reflect actual field conditions.

Some conventional devices do permit field measurements of coefficients of friction; however these devices are not appropriate for measuring coefficients of friction of floor surfaces. An example of such a device is provided in U.S. Patent No. 5,377,526, to Diekmann et al ("Diekmann"), which provides a traction analyzer that measures the coefficient of friction between a strip of paper and a surface. A constant speed motor rotates the paper, which is pressed against the surface by a force that is measured by a force measuring instrument. The force measurement at constant speeds for different surfaces allows coefficients of friction of the different surfaces to be measured.

Devices that address some of the limitations of the prior art have in the area of measurement of coefficients of friction of floor surfaces have been created. In particular, a class of devices known as tribometers has been developed for measuring surface friction. Tribometric devices determine the frictional force present when one surface is pulled or pushed across another under a determined pressure. Conventional tribometers include three main categories: dragsleds, articulated struts and pendulum-type device. The most common type of tribometer, the conventional horizontal pull slipmeter, or dragsled, is well known in the art. U.S. Patent No. 4,895,015, to English ("English I") provides a fairly advanced horizontal pull slipmeter. A drag sled and a stationary pulling mechanism are coupled together along parallel tracks. The pulling mechanism pulls the drag sled at a constant speed over the measured surface, permitting a relatively stable measurement of the coefficient of friction of the surface. Another example is disclosed in U.S. Pat. No. 4,895,015, which discloses a portable dragsled-type slipmeter in which a stationary pull mechanism applies a force to a drag sled. The drag sled with the test specimen attached is held away from the test surface until the device is activated.

Leon Bennett, M.A.E. and Eugene F. Murphy, Ph.D., *Slipping Cane and Crutch Tips*, bulletin of prosthetics research for 1977, page 71, discloses an instrumented walking cane used for testing slip resistance of cane tips on various walking surfaces. Instrumentation is provided on this device to show the angle of incidence and magnitude of the force vector at the point where the cane tip slips.

It has also been suggested to provide a variable incidence mast fitted with an articulated cane that is thrust downward at a predetermined angle in order to test the slip resistance of a cane tip. This device utilizes an electronic solenoid to provide the downward thrust. Slipmeter devices share the significant drawback that although they can be used to measure actual floor surfaces in the field, the measurements they yield do not accurately simulate the impact of the human foot on the surface.

Conventional slipmeter devices of the aforementioned type measure the static or dynamic coefficient of friction, not the "stopping" coefficients of friction, i.e., the air-to-stop stopping coefficient of friction and the dynamic-to-stop stopping coefficient of friction, which provide a more reliable measure of whether a person walking on a floor surface will perceive the surface as slippery, rather than safe. In addition, most conventional slipmeter devices share the drawback that suction forces between the test pad and a wet surface increase the measured coefficient of friction, while such forces do not operate to reduce the slipperiness of the floor surface under instantaneous impact, such as the impact of a shoe. In fact, slipmeter measurements offer little correlation with the perceived slipperiness of the floor by walking persons. Conventional tribometers yield very inconsistent surface friction results on wet or contaminated surfaces. Unreliable results occur on wet surfaces due to the effects of suction, absorption and squeegeeing. These effects result in devices where a sample surface is allowed to rest on the floor surface prior to testing, so that the contaminants are absorbed by the test specimen, squeezed out from beneath it, or create a suction effect between the specimen and the floor.

Devices have been developed to address the problem of inconsistent measurements on wet surfaces and the other limitations of horizontal slipmeters. U.S. Patent No. 4,798,080, to Brungraber ("Brungraber") provides a device for measuring the stopping coefficient of friction under field conditions. Brungraber includes a frame, a pivotal shaft, a pad of friction material, and a gravity-driven impact mechanism. The Brungraber device instantaneously impacts a test surface with a pad of friction material and permits calculation of the stopping coefficient of friction by measurement of the angle of incidence at which the pad slips, rather than sticks, upon impact with the test surface. The load in this device is applied using a gravity-dropped weight or a spring. Brungraber permits a reasonable approximation of the human gait, relative to conventional slipmeter devices, and Brungraber overcomes the interference of the action of forces of suction on the measurement of coefficients of friction.

All of the aforementioned devices, including Brungraber, still have many limitations. In particular, the devices which employ weights, springs or solenoids for the thrust force are not representative of the forces which are present during the walking process.

Additionally, the devices which require the application of thrust force by the operator are subject to operator dependent variables. These operator dependent variables tend to bias the results of the slip tests so that consistent results are difficult to achieve.

A further limitation exists in devices which utilize gravitational force. This limitation results in the inability to obtain valid results on inclined surfaces without recalibration. Since it is often necessary to determine the coefficient of friction on an inclined surface, this inability substantially limits the application of these devices.

U.S. Patent No. 5,259,236, to English ("English II") provides a tribometer that measures the air-to-stop stopping coefficient of friction, rather than the dynamic coefficient of friction, which solves some of the problems of these devices. The English machine includes a pivotal shaft, a compressed fluid drive mechanism, a head assembly, and a test pad. The English machine measures the air-to-stop stopping coefficient of friction of a surface by quickly impacting the surface at a variety of angles of incidence and determining the angle at which the test pad slips when brought into contact with the test surface. The measurement of the angle of incidence at which the test pad slips, rather than stops, after a series of test runs at different angles of the incidence, permits a calculation of the air-to-stop stopping coefficient of friction of the surface. English II permits measurement under actual field conditions, such as wet or contaminated surfaces, and it provides a measurement that more closely simulates the human gait than do conventional slipmeters. Thus, English II overcomes the interference of the action of forces of absorption, squeegeeing, and suction on the measurement of coefficients of friction that is present in conventional slipmeter devices.

Although the Brungraber and English II devices address some of the drawbacks

of conventional devices for measurement of coefficients of friction, these devices share a number of significant problems. First, although the air-to-stop stopping coefficient of friction is an improved measurement of the slipperiness of a surface as perceived by a human subject, neither machine precisely simulates the biomechanics of the human gait; in particular, while the machines permit variation of the angle and force of impact of the test pad, neither machine permits control of the other variables that affect the forces of impact between the test pad and the floor surface. Further, neither Brungraber nor English II permits control of all of the forces and measurement of all of the coefficients of friction relevant to human walking, as demonstrated by force plate experiments. Like other conventional devices for measurement of coefficients of friction, English II and Brungraber measure a single data point, rather than measuring a more complete array, or profile of data points, to enhance the user's knowledge of the "safe" or "unsafe" condition of the floor surface as a whole. Force plate experiments demonstrate that the human gait involves highly variable, complex forces. A single data point cannot reliably predict the effect of a human walking on a given floor surface.

While the Brungraber and English II devices overcome the problem of suction, they do not actually measure static coefficient of friction as conventionally defined, but instead measure one element of the stopping coefficient of friction, particularly, the air-to-stop stopping coefficient of friction. Thus, the devices yield results that do not correlate with the measurements of static coefficients of friction required by the Americans with Disabilities Act, the statute under which floor testing procedures are

regulated. The English II and Brungraber devices fall short of simulating the human gait in at least three ways: (1) they provide only a single data point, while the human gait, as demonstrated by force plates, involves a complex range of forces, (2) they cannot precisely simulate the range of approach velocities of the human foot to the floor, and (3) they are mechanically rigid systems, so the measurements are subject to errors introduced by vibration upon instantaneous impact onto the floor surface.

An additional drawback of the English II and Brungraber devices is that neither device permits the electronic recording of the measured information or the transmission of the data to a remote location.

Still another drawback of the Brungraber and English II devices is that neither device permits control of the force required to tilt the test surface into a position parallel to the floor surface, as the test surface is driven onto the surface. This force is analogous to the force required to tilt the human heel as the foot strikes the floor surface. The force to tilt the "heel" is essentially zero with the Brungraber device. On the English II device, the test surface is connected to a spring-loaded ball joint that imposes a constant, indeterminate force on the tilt of the heel.

The English II device has a number of other drawbacks. First, the compressed air drive mechanism provides a very imprecise degree of control over the force with which the test pad impacts the surface. As a result, repeated tests of the same surface under the same conditions yield differing results. Also, after use, the test pad of the

English II device does not return precisely to the initial position, further contributing to variability of measurements of the same surface under the same conditions.

The Brungraber machine has the further drawback that it does not function reliably when used on a slope, because it is gravity driven, and the components of force due to gravity are different when the machine is placed on a slope. The compressed-air force mechanism of English II solves this problem.

Also, none of the references teach the use of an integrated assembly that permits the controlled application of water or contaminants to the test surface. The inability to control test conditions contributes to the unreliability and inconsistency of measurements obtained using conventional devices.

A further drawback of the prior art is that the prior art devices do not permit control of the forces affecting the linkage of the drive mechanism to the test pad. The rigid structure of the prior art devices results in high variability of repeated tests under the same conditions.

A further drawback of the English II and Brungraber art is that these machines do not specifically control the amount of force that is required to tilt the test pad holder from perpendicular to the sensor shaft to parallel to the floor surface. Tests of prior art devices show that the coefficient of friction measurements on a typical wet ceramic tile surface can vary by up to 30%, depending on the stiffness and stickiness of the ball

joint to which the test pad is connected. If an unspecified increase in spring pressure is applied to the ball joint, the variance in the coefficient of friction increases to 50%.

A need has arisen for a device that can measure both the static coefficient of friction required by the Americans with Disabilities Act while also providing measurement of the more meaningful dynamic and stopping coefficients of friction and overcoming the many other drawbacks of conventional devices. A need has further arisen for a device that permits the user to obtain a profile of all of the various coefficients of friction under a variety of testing conditions, including velocities of the test specimen and floor conditions. Such a profile is referred to herein by the coined term "human coefficient of friction™."

Summary Of The Invention

It is an object of the invention to provide an apparatus for measuring a coefficient of friction of a surface, comprising one or more of the following features: a central processing unit; a frame; a driver, disposed on the frame, the driver responsive to and in data connection with the central processing unit; a shaft, disposed on the frame and responsive to the driver, wherein the shaft is moveable in a linear direction and an angular direction relative to the frame; a test assembly, disposed on the shaft, the test assembly including at least a test specimen; a load cell, responsive to and in data connection with the central processing unit; an adjustment assembly for adjusting the angular position of the shaft, the adjustment assembly responsive to and in data connection with the central processing unit, the adjustment assembly comprising an electronic screw drive; and

a spraying assembly, the spraying assembly in responsive to and in data connection with the central processing unit.

It is a further object of the invention to provide an embodiment of the driver wherein the driver further comprises an electronic ball screw assembly, and a clutch for adjustment of the amount of torque applied by the motor.

It is a further object of the invention to provide an embodiment of the driver wherein the driver further comprises a robotic arm.

It is a further object of the invention to provide an embodiment wherein the test assembly further comprises a compressible link, the compressibility of the compressible link responsive to the central processing unit.

The present invention provides a device for measuring static, dynamic, and stopping coefficients of friction on floor surfaces in the field under controlled environmental conditions and with precise simulation of the forces involved in the human gait. The device includes a frame, a sensor shaft that is mounted on the frame to permit pivoting of the sensor shaft to a variety of angular positions relative to the measured surface, a sensor assembly, including a load cell, mounted on the sensor shaft that contacts the surface and measures and outputs as a signal the precise force with which the sensor assembly contacts the surface and the precise position, velocity and acceleration of the assembly at all points from the time the sensor contacts the surface

until the test cycle is complete, a slide assembly, which may be a ball screw or other screw drive type assembly, that permits movement of the sensor assembly along a longitudinal axis of the sensor shaft toward the surface to be measured, and a driver, which may be a step motor, a servo, a robotic arm or other controllable mechanism for imparting force and which may include a clutch, that permits the control of the applied forces to test the surfaces as well as the precise, real-time positioning of the sensor assembly relative to the surface. The device may further include a swivel ball and head assembly for the sensor assembly, an interchangeable sensor pad, and a compressible coupling or air bag that permits precise adjustment of the absorption of energy between the load cell and the sensor pad. The compressible coupling/air bag and the step motor/ball screw assembly permit the adjustment of the device to simulate a wide variety of human gaits, particularly to mimic the absorption of energy by human joints such as the ankle and knee. The device may further include an assembly for spraying water or other contaminants in a controlled manner onto the floor surface prior to measurement. The device may further include means for inputting, storing, retrieving and transmitting the data regarding the position, forces, velocity, and acceleration of the test surface that impacts a floor surface.

The device of the current invention offers many advantages over existing devices. First, the present invention allows for adjustment, control, measurement, storage, retrieval and transmission of data regarding a number of variables that are components of the interaction of the human gait with a floor surface, unlike the conventional devices that measure only a single data point, that provide no means for

storing, retrieving or transmitting data, and that permit control only of the contact angle and, to a very limited extent, the force with which the test surface impacts the floor surface. In particular, the present invention permits the user to control and measure the velocity and force of impact, while the weight or spring on the Brungraber machine and the force of the English II machine are set by the manufacturer.

A further object of the invention is to provide a ball screw drive assembly to precisely move a sample surface to instantaneously impact a floor surface in a controlled manner. Although the force of impact can be varied in the English II device, the user is instructed to use a constant air pressure and the device is not intended to profile the slip resistance of the surface over a range of forces.

In an alternative embodiment, the present device also permits control and measurement of the force required to tilt the surface on which the test specimen is mounted to a position parallel to the floor surface, in order to simulate the tilt of the human heel as it strikes a floor surface. In particular, the present invention permits control and measurement of the velocity of impact and the velocity of sliding of the test pad that is used to test the surface. In contrast, the test velocity in Brungraber is constant by virtue of the height of the fall of the weight and the test pad velocity in English is constant for a given example machine based on the constant air pressure of the air cylinder. In English II, if the air cylinder is of a different length, or if the starting height above the floor of the pad or cylinder shaft is different, or if the diameter of the air tubing is different, resulting in different filling rates, then the

manufacture of the example machine changes the velocity of impact, but not in a way that is controlled by the user.

The present invention also permits control and measurement of the velocity of impact; that is, the velocity of movement of the test pad: (a) across the surface after breaking the static coefficient of friction and entering into the measurement of the dynamic coefficient of friction, or (b) approaching the surface from the air. Prior art devices do not permit measurement or control of the velocity of impact. It is a further object of the invention to permit control of the angle impact of the test pad.

It is a further object of the invention to control the compressible linkage force, which is the force that affects the degree to which the test pad is compressed toward the drive shaft when it impacts the surface to be tested. This force may be adjusted to simulate the absorption of energy due to the compressibility of the human ankle and knee joints when the foot strikes a floor.

The present invention further provides for the creation, storage, retrieval and graphical representation of a stream of real-time data profile regarding all of the measured coefficients of friction at any point during the path of the test pad. Thus the invention provides the precise simulation of the forces identified through force plate experiments, while retaining the portability and other advantages of prior art devices. The purpose of controlling all of the forces applicable to the impact or movement of a test pad on a surface, is to permit the user to extract more, more reliable, and more

effective data about the slip resistance of the floor under conditions that more closely mimic the variations in human gait conditions and changing conditions of the floor surface. The present invention can test the floor over a range of variables and do it in a reasonably short period of time.

Another feature of the present invention that distinguishes it from the prior art is that the present invention can accurately measure static, stopping and dynamic coefficients of friction, can provide a data profile of floor slip resistance, and can make all of these measurements conveniently over a wide range of human gait conditions. The prior art machines can change one or two variables with great inconvenience, usually including substantial redesign and rebuilding of the machine.

A further object of the invention is to provide a compressible, fluid-filled coupling between the drive mechanism and the sensor surface that is designed to simulate the shock absorbing compressibility of the human ankle.

In an alternative embodiment of the present invention, the user is able to control and measure the force required to tilt the test pad to become parallel to the floor after initial impact of the leading edge of the pad onto the floor. Thus, the user is able to resolve two different forces into accurately controlled and measured components, namely, the force required to tilt the "heel" of the test pad from an initial angle to a position parallel to the floor surface, and the force of impact directed towards the floor surface by the pad due to the forward motion of the sensor shaft. If the force required

to tilt the "heel" is not zero, or if the force has significant variance, then the force required to tilt the heel contributes significantly to the distribution of vertical and horizontal forces that impact the test pad, rendering test measurements of very high variance. The present invention permits the user to set the force required to tilt the heel at a near zero value with very low variance, permitting very accurate, consistent measurements without interference from the contribution of forces required to tilt the test pad. By controlling the heel tilting pressure, the present invention permits the user to measure coefficients of friction with as much as 50% less variability than conventional devices, particularly as the coefficient of friction becomes lower, the most dangerous situations for floors.

In sum, the present invention is a device that can measure both the static coefficient of friction required by the Americans with Disabilities Act while also providing measurement of the more meaningful dynamic and stopping coefficients of friction and overcoming the many other drawbacks of conventional devices. A test protocol of the present invention permits measurement of the "human coefficient of friction™," a complete data profile of several other known coefficients of friction under a variety of simulated gait conditions and surface conditions.

<u>Brief Description Of Drawings</u>

FIG. 1 illustrates a perspective view of the computer stand, computer, and cover of a portable device for measurement of coefficients of friction in accordance

with the preferred embodiment of the present invention.

FIG. 2 illustrates a perspective view of a portable device for measurement of coefficients of friction in accordance with the preferred embodiment of the present invention.

FIG. 3 illustrates a schematic of the electrical connections of the testing device.

FIG. 4 illustrates a more detailed view of an embodiment of the invention.

FIG. 5 illustrates a side view of an alternative embodiment of the device as used to measure static and dynamic coefficients of friction, in a position prior to commencement of a test cycle.

FIG. 6 illustrates a side view of an alternative embodiment of the device as used to measure static and dynamic coefficients of friction, in a position reached during a test cycle.

FIG. 7 is a schematic view of the axis angle regulation mechanism of the present device.

FIG. 8 is a schematic of an alternative embodiment of the compressible link of the present device.

FIG. 9 is a schematic of an alternative embodiment of the compressible link of the present device.

FIG. 10 is a schematic of an alternative embodiment of the compressible link of the present device.

FIG. 11 illustrates a side view of the device, including the axis angle regulation mechanism, in a position ready to commence testing.

FIG. 12 illustrates a side view of the device during a test cycle.

FIG. 13 illustrates a side view of the testing device during a test cycle.

FIG. 14 illustrates the testing device in a position assumed during a test near the end of a test cycle.

FIG. 15 illustrates an example of a graphical display of the data gathered during a series of test cycles of the device, i.e., a typical "human coefficient of friction."

FIG. 16 illustrates an alternative embodiment of the present invention, wherein the means for driving the test specimen is a robotic arm.

FIG. 17 is a schematic diagram illustrating the operation of the central

processing unit with the other elements of the testing device.

FIG. 18 is a flow chart representing steps of using the central processing unit to operate the testing device.

FIG. 19 is a flow chart representing steps of a basic action test cycle of the present invention.

FIG. 20 is a flow chart representing steps of a test sequence of the present invention.

Detailed Description Of The Preferred Embodiments

Referring to FIG. 1, there is illustrated a testing device 10, in accordance with the preferred embodiment of the present invention. The testing device 10 is housed in a cover 11. The testing device 10 is electrically connected to a computer or CPU 22 that is disposed on a portable CPU 22 support means 27, which may be a portable cabinet on wheels or a computer stand. Alternatively, the CPU 22 may be a laptop computer or other portable computer. The testing device 10 may be connected to the CPU 22 and to any conventional electrical power source by conventional wire cables. A schematic of the connection of the CPU 22 to other elements of the testing device 10 is provided in FIG. 3. The CPU 22 could also be connected to the testing device 10 by infrared transmission, laser transmission, or other known means of data transmission.

Referring to FIG. 2, there is illustrated a testing device 10, in accordance with an embodiment of the present invention. The testing device 10 is constructed of a frame 12 onto which the remaining elements of the testing device 10 are mounted. Those elements include a driver 14. The driver 14 may generally include a mechanism for imparting force, such as a step motor or servo, as well as a mechanism for directing the force, such as a ball screw assembly or other electronic screw drive, or a robotic arm. In an embodiment of the invention a ball screw assembly drives a shaft 18 with a controlled linear force, velocity and acceleration. The testing device 10 may also include a test assembly 16, for attaching a specimen 20 to the shaft 18, a CPU 22 (not shown), for controlling the driver 14 to move the shaft 18 to move the specimen 20 in contact with a test surface and for measuring, storing, and retrieving data regarding the position, velocity and acceleration of the specimen 20 during testing, an adjustment assembly 24, for adjusting the angle of incidence at which the specimen 20 contacts a test surface, a spraying assembly 32, connected to and controlled by the CPU 22, a compressible link 34, disposed between a sensor pad base 61 and the shaft 18, to control the absorption of energy between the sensor pad base 61 and the shaft 18, and a load cell 36, in electrical connection and data connection to the CPU 22, for measuring the force of impact of the specimen 20 on the test surface. The test assembly 16 comprises the load cell 36, the compressible link 34, the sensor pad base 61, the test specimen 20 and other components detailed below. The load cell may include a load sensor 250 that measures the load on the load cell 36 and provides a data output of the load at all points in time.

Referring to FIG. 3, the CPU 22 is connected to the driver 14, the load cell 36, the spraying assembly 32, and the adjustment assembly 24 by conventional means, which may be conventional coaxial cables or other means of data transmission, such as infrared, radio or laser. The connections to the CPU 22 may also include electrical connections to a power source (not shown), which may be computer-controlled, for each of the components.

Referring to FIG. 4, a schematic of the driver 14 is provided. In an embodiment of the invention, the driver 14 may be an electronic screw drive, such as a ball screw assembly, of the type commercially available and used in applications such as ink jet printers, precision machine tools, or the like. The ball screw assembly may be driven by any conventional motor, servo, or similar device, such as a step motor 15. References to the step motor 15 herein should be understood to encompass any conventional electromechanical drive mechanism for imparting force for the driver 14. The step motor 15 may include a clutch 120, which may be electronic or mechanical, which may be used to adjust the amount of torque applied by the motor if force is applied without movement. References to the step motor 15 herein should be understood to include a step motor that may include or be associated with a clutch. The step motor 15 is in electrical connection to the CPU 22, and via the step motor 15 the CPU 22 can provide extremely precise control of the position, velocity, force, and acceleration of the shaft 18 that is connected to the driver 14, while also recording a stream of data regarding the exact position, velocity, force and acceleration of the shaft 18 at all points in time during the testing process. The CPU 22 is able to obtain such

measurements directly via the output of the number of revolutions of the step motor 15, which is calibrated to indicate the degree to which the shaft 18 moves in response to a given number of revolutions of the step motor 15. The driver 14 is able to adjust the position, velocity and acceleration of the specimen 20 at intervals dependent on the speed of the microprocessor of the CPU 22 and the input/output capacity of the components, but is preferably capable of 100 or more adjustments per second.

Referring to FIG. 2, in an embodiment of the invention, the driver 14 further includes a pair of slide rails 17, a ball screw 19, a slide table 21, and a sensor mount 23. The sensor mount 23 is rigidly connected to the shaft 18 at an end distal from the test surface. The sensor mount 23 is disposed on and rigidly connected to the slide table 21. The slide table 21 is slidably disposed on the two slide rails 17, so that the slide table 21 permits the sensor mount 23 to move back and forth along the longitudinal axis of the shaft 18, correspondingly moving the shaft 18 and the test assembly 16. The slide table 21 is rigidly connected at a position central to the longitudinal axis of the shaft 18 to the ball screw 19. In an alternative embodiment, the sensor mount 23 may be mounted to the slide table 21 by one or more hinges, so that the sensor mount 23 may rotate in an angular direction relative to the slide table 21. The ball screw 19 moves back and forth along the longitudinal axis in response to the drive of the step motor 15, thus driving the sensor mount 23, shaft 18 and test assembly 16 along the longitudinal axis of the shaft 18. The step motor 15 permits precise control of the ball screw 19, which permits precise control of the position, velocity and acceleration of the sensor mount 23 and all of the connected elements,

including the specimen 20. The step motor 15 and the slide rails 17 are rigidly disposed on a slide assembly base 25, which is constructed of a rigid material, such as metal or hard plastic.

Referring to FIG. 5 and FIG. 6, an alternative embodiment of the present invention, a different device for applying force to the sensor pad base 61, is provided. This alternative may also be used as a modification to conventional tribometers, such English II. Applying this alternative to the English II device would permit such devices to measure true static and dynamic coefficients of friction of the test surface, in addition to measuring the air-to-stop stopping coefficient of friction, as these devices currently do. Referring to FIG. 5, a mating block 77 is provided, fashioned to mate with the side of the sensor pad base 61. Although the mating block 77 is mated to the sensor pad base 61 in the preferred embodiment of this alternative embodiment of testing device 10, the mating block 77 could alternatively be positioned to mate with any other component of the test assembly 16, or with the shaft 18. The mating block 77 is positioned on the end of a shaft 79, the shaft 79 being positioned substantially horizontal to the test surface, so as to be capable of imparting force on the sensor pad base 61 that is substantially parallel to the test surface. There is further provided a load cell/strain gauge 75 which is positioned along the shaft 79 in a position capable of measuring the force imparted on the sensor pad base 61 by the shaft 79. At an end of the shaft 79 distal from the sensor pad base 61 is positioned a linear motion device 78 that is capable of imparting force on the shaft 79. The linear motion device 78 is preferably a controllable, ball screw type assembly to control velocity of linear motion

and record instantaneous position, velocity and acceleration of the test specimen 20 during a test procedure. The linear motion device 78 permits the user to control force and velocity of linear motion of the test assembly 16, thus permitting calculation of the static and dynamic coefficients of friction of the test assembly 16 on the test surface. The linear motion device 78 may be of a ball/screw type assembly, or other conventional device for imparting controlled linear force. The linear motion device 78 is in electrical connection with the CPU 22 and a power source, permitting control of the linear motion device 78 by the CPU 22 and permitting the delivery of position data from the linear motion device 78 to the CPU 22. The linear motion device 78 could also be of a conventional type not controlled by CPU 22, or could provide output directly through a conventional display, without convenying data to the CPU 22, or both. The linear motion device 78, shaft 79 and load cell/strain gauge 75 may be added to a device such as English II to expand the capability of such a device to include measurement of static and dynamic coefficients of friction. The load cell/strain guage 75 may also be independent of the CPU 22, providing an independent display of output.

As may be inferred from the foregoing discussion, any number of other means may be envisioned for applying appropriate forces to a test specimen in order to permit calculation of the coefficients of friction measured by the present invention. Such force applying means could be conceived as modifications of the preferred embodiment of the present invention, as additions to or modifications to prior art devices such as English II, as in the alternative embodiment described in the preceding paragraph, or

could be incorporated into devices of entirely different structure. The preferred embodiment of the present invention is described in detail herein, but any other embodiments capable of applying and measuring forces in the manner of the present invention are intended to be covered by this disclosure. Examples of other embodiments that could apply and measure forces in the manner of the present invention would include an articulated robotic arm controlled by a central processing unit or a prosthetic arm assembly controlled by a central processing unit, each of which could control and measure a range of forces and velocities of a test specimen, permitting the user to conduct a series of test cycles with varying surface conditions. A schematic of a robotic arm is provided in FIG. 16.

Referring to FIG. 16, a test attachment 16 of construction substantially similar to the test attachment 16 of the preferred embodiment of the testing device 10 is attached to a robotic arm 100. Robotic arm 100 is linked via one or more hinge pins 104 to a vertical arm 103 that is fixed to a rigid base 102 that is disposed on a test surface. The robotic arm 100 may be constructed as a series of rigid links 106 linked by hinge pins 104. A plurality of motion-generating and force-sensing components 108 may be connected to the rigid links 106 by additional hinge pins 105. The motion-generating and force-sensing components 108 are connected to the rigid links 106 at points distal from the connections among the rigid links 106, so that the motion-generating and force sensing components 108 can exert leverage on the rigid links 106, permitting movement of the robotic arm 100. Each motion-generating and force-sensing component 108 includes a sensor 110, capable of sensing the force on the

motion-generating and force-sensing component 108, and a force imparting component 112, both in electrical connection to a CPU 22 of the type described in the preferred embodiment of the testing device 10. Control of the CPU 22 permits control of the movement of the motion-generating and force-sensing component 108, the rigid links 106 and the robotic arm 100. By controlling movement of the robotic arm 100, the robotic arm 100 may be used to cause the test attachment 16 and attached test specimen 20 to impact the floor in a manner similar to the manner of the preferred embodiment of the testing device 10.

One can envision any number of alternative embodiments for imparting force on test specimen 20 in order to carry out the test cycles of the testing device 10. In addition to the robotic arm 100 of FIG. 16, one could envision interchangeable combination of CPU-controlled force, measurement and power applied through cables and pulleys, pistons, airbags, magnetic slides, ball screws, solenoids, or linear motors as each of the respective force-imparting components of the testing device 10, including the driver 14, the axis angle regulation mechanism 24, represented by the screw jack 50 in the preferred embodiment, the compressible link 34 and the motion-generating and force-sensing components 108 of the robotic arm embodiment of the present device or of a prosthetic arm embodiment of the present device. Any conventional means for imparting and measuring force in a controlled manner and sensing the resulting movement of the test specimen 20 could be configured to engage the testing device 10 in the data gathering cycles described below.

Referring again to FIG. 2 and FIG. 4, in the preferred embodiment of the testing device 10, the specimen 20 is a material suitable for testing on a surface, such as the material used in the sole of a shoe, with a backing that permits magnetic attraction or mechanical attachment. The specimen 20 is attached to the test assembly 16, which includes, as further illustrated by FIG. 4, the load cell 36, the compressible link 34, a swivel ball shaft 37, a swivel ball 38, a spring 40, a swivel head 42, a sensor base 44, and a sensor pad base 61. The specimen 20 will be driven into contact with the test surface on which the testing device 10 is placed. The static, stopping and dynamic coefficients of friction between a variety of test specimens 20 and test surfaces can be measured by varying the combination of the test specimens 20 and the test surfaces. The load cell 36 is disposed on the shaft 18 and is in electrical connection with the CPU 22, so that the CPU 22 can receive, store and manipulate data from the load cell 36. The load cell 36 is of a conventional type that generates a continuous stream of data that indicates the force with which the test assembly 16 impacts the floor surface. The load cell 36 is disposed on the sensor shaft 18 at an end proximal to the driver 14. Disposed along the shaft 18 at a position more distant from the driver 14 than the load cell 36 is the compressible link 34, which may be of a conventional material such as flexible rubber. In an alternative embodiment of the present invention, the compressible link 34 is of a material and construction, such as a fluid filled bag, that permits control of the force required to compress the link in order to mimic the amount of energy absorbed by a human joint. In this alternative embodiment, the amount of fluid in the compressible link 34 may be controlled to optimize the link to mimic the compressibility of the human ankle when a foot strikes a floor surface. The

compressible link 34 protects the load cell 36 from shock and extends loading for detection, collection and analysis of force data. The compressible link 34 permits the testing device 10 to overcome the problems of interference through shock that are present in rigid prior art devices. The compressible link 34 is preferably of a fluid filled bag, but could be made of a slowed spring, such as a liquid-filled shock absorber with spring, a slowed spring backed up by a load cell, or a combination of a load cell/compressible link based on opposing magnetic fields that can be simultaneously used to control the force and speed of compressibility but that can also record the continuous instantaneous force being created between the ends of the compressible link 34. A schematic of a compressible link 34 based on opposing magnetic fields is provided in FIG. 8. The mechanical assembly of the compressible link 34 can be similar to an air cylinder, except that the opposing resistance is created by the magnetic fields and can be tailored to mimic the compression of human soft tissue in the joints during walking.

Referring to FIG. 8., a schematic of one alternative embodiment of the compressible link 34 is provided. The compressible link 34 includes a first link component 80 and a second link component 82, linked by a pair of compressible bellows 84. The first link component 80 includes a first magnetic field generator 86 and a first array of proximity sensors 88. The first array of proximity sensors 88 is disposed about the circumference of the first link component 80. The second link component 82 includes a second magnetic field generator 90 and a second array of proximity sensors 92. The second array of proximity sensors 88 is disposed about the

circumference of the second link component 82. The magnetic field generators 86 and 90 may be of any conventional type, such as coiled electrical wire, and are in electrical connection to a power source and to CPU 22. The polarity of the magnetic field generators 86 and 90 is such that the magnetic field generators 86 and 90 cause first link component 80 and the second link component 82 to repel each other. The strength and distribution of the magnetic field betwen the two magnetic field generators 86 and 90 is controlled by CPU 22 and determines the degree of compression and/or tilting of the compressible link 34 under a given applied or measured force. The compression and/or tilting is measured by the first and second arrays of proximity sensors 88 and 92, which are in communication with CPU 22, so that the CPU 22 can be used to control and record the compressibility and the tiltability of the compressible link 34. The compressible link 34 of FIG. 8 could be of any shape, e.g., oblong, circular, cylindrical or oval.

Referring to FIGS. 9 and 10, alternate embodiments allowing for compression, but not tilting, for the compressible link 34 are provided. Referring to FIG. 9, in the case of a cylindrical compressible link 34, the magnetic field generators could be slidably positioned along an internal longitudinal axis of a cylindrical compressible link, with the magnetic field generators being coupled with the drive shaft 18 and the test attachment 16 at each end of the cylinder. Referring to FIG. 10, a slide-type compressible link could also take a dovetail shape, with each slidable magnetic field generator being positioned in a slot along an internal longitudinal axis of the compressible link. In each case, the CPU controls the compressibility of the link by

controlling the magnetic field, and position sensors, such as electronic calipers, permit measurement of the distance, velocity and acceleration of the compression of the link.

Disposed still more distal from the driver 14 along the axis of the shaft 18 and rigidly connected to the compressible link 34 is the swivel ball shaft 37, upon which is rigidly disposed the swivel ball 38, which is of a conventional, durable material, such as stainless steel or hard plastic. Disposed over the swivel ball 38 is a swivel head 42, which is rigidly connected to the sensor base 44. The swivel head 42 permits the sensor base 44 to swivel about the swivel ball 38 through a wide range of degrees of freedom, simulating the degrees of freedom of the human ankle. The swivel head 42 should be constructed to fit precisely over the swivel ball 38, in a manner that causes the friction between the swivel head 42 and the swivel ball 38 to be negligible during the testing cycles of the testing device 10. The spring 40, holds the end of the swivel head 42 in a position approximately perpendicular to the shaft 18 prior to and after testing. In an alternate embodiment, the compressible link 34 is disposed between the swivel head 42 and the swivel ball 38, rather than between the load cell 36 and the swivel ball shaft 37. The sensor pad base 61 is magnetized to permit interchangeability of different specimens 20.

Referring now to FIG. 2, the slide assembly base 25, bearing the driver 14 and linked to the sensor shaft 18 and test assembly 16, together with all constituent elements, is pivotally mounted by a pair of hinge pins 45 between a pair of arms 46, which are in turn pivotally connected to the frame 12 by another pair of hinge pins 47,

permitting adjustment of the angle of incidence between the longitudinal axis of the shaft 18 and the test surface. The arms 46 also are adjustable to define a test angle 59, defined as the angle between the shaft 18 in a given position and the shaft 18 in a vertical position. The arms 46 are constructed of a durable, rigid material, such as stainless steel or hard plastic. The material for the arms 46 and frame 12 is selected to provide an overall weight for the testing device 10, including the cover 11, of at least ten pounds, thus rendering the device stable on the test surface under test conditions. The arms 46 may be extended and connected at a position distal from the floor surface, permitting them to serve as a handle for carrying the testing device 10.

Referring to FIG. 7, also pivotally connected to the arms 46 by another pair of hinge pins 49 is a screw 48, which is responsive to a conventional electrical screw jack 50, which is pivotally mounted by another pair of hinge pins 51 to the frame 12. The screw 48 includes a thread 53 that is responsive to a receiving thread 55 of the screw jack 50. The screw jack 50 includes an electric adjustment motor 57, which drives the receiving thread 55 clockwise or counter-clockwise, so that operation of the screw jack 50 moves the screw 48 along its longitudinal axis and increases or decreases the distance between the ends of the arms 46 that are distal from the test surface and the frame 12, thus pivoting the arms 46 about hinge pins 49, changing the angle of incidence between the arms 46 and the frame 12 and inducing a corresponding change in the angle of incidence between the test assembly 16 and the test surface. The screw jack 50 is calibrated so that the exact change in the angle of incidence between the test assembly 16 and the test surface that corresponds to a revolution of the electric

adjustment motor 57 is known and may be programmed into the CPU 22. The screw jack 50 is illustrated in schematic form in FIG. 7. The screw jack 50 and electric adjustment motor 57 are of a conventional type readily available from electronics manufacturers, such as Thompson Manufacturing. The screw jack 50 includes is in electrical connection with the CPU 22, so that the CPU 22 receives an output of the revolutions of the electric adjustment motor 57 of the screw jack 50, which, along with the calibration information, permits precise control and measurement of the angle of incidence and the rate of changes of the angle of incidence. The CPU 22 permits the user to vary and record the position of the screw jack 50 and thus the position of the arms 46 and the angle of incidence of the shaft 18 relative to the test surface. These variations may be made simultaneously with movements of the test specimen 20 via the driver 14. The use of the CPU 22 to calculate the position of the arms 46 and the angle of incidence of the shaft 18 avoids the need for hand measurements of the angle of incidence through a protractor mounted on the device, as in conventional tribometers.

Between test cycles, CPU 22 may be used to control the axis angle regulation mechanism 24 via screw jack 50 in order to position the test specimen 20 in a position where the test specimen 20 is easily interchanged or treated by cleaning or surface dressing procedures. The test specimen 20 is preferably detachable from test attachment 16, so that the test specimen 20 may be easily substituted between test cycles.

The testing device 10 may further include a spraying assembly 32, pivotally mounted on the frame 12 in a position proximal to the position of the floor surface that is impacted by the specimen 20. The spraying assembly 32 may further include a pair of reservoirs 56, for holding selected contaminants, such as water or liquid soap, and a conventional pump 58, for spraying the water or contaminants on the test surface. The pump 58 may be electrical and in electrical connection with the CPU 22, permitting the user to control the amount and type of contaminant that is sprayed on the surface.

Referring to FIG. 1, the CPU 22 may be located on a separate support device 27. Alternatively, the CPU 22 may be located on the slide assembly base 25, or on the frame 12. The CPU 22 includes conventional user interface means 67, including a keypad 68 and a graphical display 70. The CPU 22 is programmed by conventional means to control the screw jack 50, the driver 14, and the spraying assembly 54. The CPU is also programmed by conventional means to collect data regarding the velocity, force and acceleration of the specimen 20 from the load cell 36 and to calculate, store and display in graphical format the various coefficients of friction heretofore described. In the alternative embodiment, the CPU 22 may also be connected to the compressible link 34 to control the compressibility of the compressible link.

Referring to Fig. 17, further information regarding the operation of the CPU 22 is provided. The CPU 22 may be a conventional computer with standard components including a microprocessor 133 and an operating system 135. The operating system is preferably an operating system capable of supporting a graphical user interface, such as

the Windows® operating system provided by Microsoft. The operating system 135 controls a number of application programs 139. The application programs may include an application program 136 for control of the various elements of the testing device 10. The application program 136 may also control input/output devices of the CPU 22, so that the application program 136 can send data to the elements of the testing device 10 and the application program 136 can receive data from those elements for further processing. The CPU 22 may also include a communications application program 138, a data storage, manipulation and retrieval application program 140, or "database program," and a user interface control application program 142. The application programs permit the user to control the operation of the CPU 22 to control the test device 10.

The CPU 22 may further include one or more input/output devices 144, 146. The CPU 22 may further include a communication device 148, such as a modem. The input/output devices 144, 146, the communications device 148, the display 70, and the keyboard 68 may all be connected by conventional means, such as a bus 141. The bus 141 permits data and electrical signals to be sent among the application programs and the various devices, so that the application programs control the devices in response to signals from the user or the devices.

The CPU 22 may include an application program 136 for input and output control data for operation of the testing device and for collection of data provided by the testing device. The application program 136 may be programmed by conventional means using any conventional programming language. The application program 136 controls an

input/output device 146 that is connected by a data connection 150. The data connection 150 can be used for connection to a remote computer 129 or for connection to the testing device 10. The testing device 10 may include a bus 131 that provides for distribution of data from the CPU 22 to the various components of the testing device 10, or, alternatively, the CPU 22 may have separate data connections to each of the components of the testing device 10. Thus, the bus 131 permits data input and output to and from the driver 14, the load cell 36, the spraying assembly 32, and the adjustment assembly 24.

The driver 14 may also include control electronics 121 that are receptive to the data from the CPU 22, so that the input/output control application 136 can deliver data to the control electronics 121 to control the operation of the driver 14. The control electronics may include a sensor 127 which may provide output through the bus 131 and the data connection 150 to the input/output control application 136, so that the CPU 22 may receive data from the sensor to determine the forces, velocities, accelerations, and other information regarding the operation of the control electronics 121 and the driver 14. The input/output control application may then transfer the data via the bus 141 of the CPU 22 to the data storage, manipulation and retrieval application 140, which may be a conventional database management application. Thus, data storage, manipulation and retrieval application 140 may store data regarding the operation of the driver 14 at all points in time.

The testing device 10 may also include a load cell 36 which may include a load sensor 250. The load sensor 250 may provide output via the bus 131 and the data

connection 150 to the application program 136. The application program 136 may then receive the data from the load sensor 250 and transmit it to the data storage, manipulation and retrieval application 140. The data storage, manipulation and retrieval application 140 may thus store historical information regarding the loads imposed on the load cell 36 during operation of the testing device 10.

The testing device 10 may also include the spraying assembly 32. The spraying assembly 32 may include a spraying sensor 123. The spraying sensor 123 may measure, record and output the amount of water or other fluid that is to be sprayed on the test surface. The spraying sensor 123 may then transmit information regarding the amount of fluid deposited in a given test cycle via the bus 131 and the data connection 150 to the application program 136. The application program 136 may then transfer the data from the spraying sensor 123 to the data storage, manipulation and retrieval application 140 via the bus 141.

The testing device 10 may also include the adjustment assembly 24. The adjustment assembly 24 may include adjustment control electronics 139 and an adjustment sensor 125. The adjustment control electronics 139 may be responsive to signals sent via the data connection 150 and the bus 131 from the application program 136 via an input/output control device 146. Thus, the CPU 22 may be programmed to control the operation of the adjustment assembly 24 through the adjustment control electronics 139. The adjustment assembly 24 may further include an adjustment sensor 125, which may sense the position of the adjustment assembly 24, so that the angle of the testing device 10

can be controlled and measured at any given time. The data from the adjustment sensor 125 can then be sent via the bus 131 and the data connection 150 to the application program 136 for transfer via the bus 141 to the data storage, manipulation and retrieval application 140. Thus, the data storage, manipulation and retrieval application 140 can be used to store historical information regarding the angle of the testing device 10 at all points in a test cycle.

The data connection 150 between the CPU 22 and the testing device 10 may be any conventional means, including a wire or cable capable of data transmission, infrared transmission, radio frequency transmission, or other data transmission means. The data connection 150 can be a computer network, such as the Internet. The data connection 150 may also provide a connection to a remote computer 129. The data connection can thus permit an application program operating on the remote computer to control the application program 136 of the CPU 22. Thus, all operations on the CPU 22 can be operated via a remote computer 129 through the data connection 150. Thus, the CPU 22 can control the testing device 10 at a given location via remote connection through a computer network such as the Internet.

Referring to FIGS. 11 through 14, the operation of the testing device 10 to determine the coefficients of friction between a test specimen 20 and a test surface can be understood. FIGs. 11 through 14 illustrate a test cycle of the testing device 10. The device is in the position illustrated in FIG. 11 prior to actuation, with the specimen 20 held in a position above the test surface. When the user instructs the CPU 22 to actuate

the device via the keypad 68, the user may select a test cycle for the testing device 10. A test cycle could specify any range of measurements, from a single data point, to a series of profiles of all of the coefficients of friction described above, the air-to-stop stopping coefficient of friction, the static coefficient of friction, the dynamic coefficient of friction, and the dynamic-to-stop stopping coefficient of friction, at a variety of angles of incidence and velocities and under a variety of test surface conditions. In a typical test cycle, upon initiation of the cycle, the ball screw assembly driver 14 drives the ball screw 19, which moves the slide table 21 along the slide rails 17 along the longitudinal axis of the ball screw 19 toward the test surface. The movement of the slide table 19 moves the sensor mount 23, which drives the shaft 18 toward the test surface. Referring to FIG. 12, the movement of the shaft 18 drives the test assembly 16 toward the surface, causing the specimen 20 to strike the surface. FIG. 13 illustrates the position of the testing device 10 in a configuration reached as the specimen 20 impacts the test surface. In an alternative embodiment, the resistance of the compressible link 34 is calibrated to simulate the absorption of energy by the human ankle as the heel of the foot strikes a floor surface. The continued driving of the ball screw 19 toward the test surface tilts the specimen 20 into a position parallel to and in contact with the test surface through rotation of the swivel head 42 about the swivel ball 38, as illustrated in FIG. 13. In the preferred embodiment, there is negligible friction between swivel head 42 and swivel ball 38, so that the specimen 20 tilts easily into a position parallel to the test surface. In an alternative embodiment, the testing device 10 permits control and measurement of the force required to tilt the specimen 20, so that the contribution of the force required to tilt the specimen 20 can

be included in the calculation of the coefficient of friction. The means to control and measure the force required to tilt the specimen 20 could include springs, air cylinders, air bags, magnetic springs, or any of the types of force control and measurement devices used in robotics or machine control.

After the specimen 20 is parallel to and in contact with the test surface, the force created by the driver 14 then drives the specimen 20 along the test surface, as illustrated in FIG. 14. After the specimen 20 has impacted the test surface, the force of the driver 14 can be varied precisely at very small time intervals, providing the ability to mimic the exact application of forces at each point during the human gait, as determined by force plate experiments and other methods of observation. Gravity drop devices are unable to mimic the build-up of force typical of the human gait, because all of the force is applied virtually instantaneously to the surface. Although air pressure-driven devices provide for some force build-up, the degree and timing of the build-up cannot be precisely controlled to mimic the variations of forces in the human gait. The application of force through ball screw driver 14 permits the present invention to be used on slopes, since the force applied to the test surface is the same at any angle of test surface.

During certain test cycles of the present invention, such as the air-to-stop cycle, the application of force by the specimen 20 is over a sufficiently brief duration, approximately one-tenth of a second, to avoid the affects of suction, squeegeeing, and absorption that are caused by moisture or contaminants on the test surface. Repeated

applications at different force levels permits the load cell 36 to measure the components of the forces required to halt momentarily the movement of the test specimen 20 as it contacts the test surface, to commence movement of the specimen 20 along the surface, to move the specimen 20 along the surface, and to stop the specimen 20 on the surface. Combinations of these four steps can be constructed to create a full test protocol of the testing device 10. In particular, movements of the specimen 20 can be used to create "basic action test cycles," or simply "test cycles." These terms, as used herein, refer to the movements of the specimen to measure the different types of coefficient of friction described more particularly below. For a given test cycle, or type of coefficient of friction, the term "test sequence" should be understood to mean a test that is conducted by varying the parameters of the test for a given test cycle, such as velocity, test surface, contamination and the like. For example a test sequence could consist of measuring the stopping coefficient of friction (in a test cycle) repeatedly for different velocities and for different levels of floor moisture. A "test protocol," as used herein, should be understood to mean a test of a surface that consists of more than one test sequence, more than one test cycle, or both.

The data delivered from the load cell 36, the driver 14 and the electronic screw drive 50, and in an alternative embodiment, the load cell/strain guage 75, permit the CPU 22 to calculate and store the air-to-stop stopping, static, dynamic, and dynamic-to-stop stopping coefficients of friction according to the definitions described herein.

To determine the air-to-stop stopping coefficient of friction, the axis angle

regulation mechanism 24 is controlled by the CPU 22 to decrease test angle 59 under a series of applications of force through driver 14 to the test specimen 20 until the CPU 22 measures an instantaneous increase in the forces as the test specimen 20 momentarily stops upon striking the test surface. The forces required to move the test specimen 20 immediately prior to the increase in forces yields a measurement of the air-to-stop stopping coefficient of friction.

In order to calculate the static coefficient of friction, the shaft 18 is positioned in a substantially vertical position, so that the test angle 59 is at zero. The device 10 is then instructed via the CPU 22 to move the test specimen 20 toward the test surface at a known pressure, such as five pounds per square inch. The CPU is then instructed via the CPU 22 to increase the test angle 59 via the electrical screw jack 50. When static friction is exceeded, the test specimen 20 will begin to slide and the CPU 22 will measure, via the test specimen 20, an instantaneous drop in the forces impacting the test specimen 20. The static coefficient of friction is the coefficient of friction immediately prior to the drop in the forces imposed on the test specimen 20. The CPU 22 is programmed to calculate and store the static coefficient of friction for a given test surface.

The dynamic coefficient of friction is calculated immediately subsequent to the calculation of the static coefficient of friction as described above. Upon the instantaneous drop in forces required to move the test specimen 20 as the angle of

incidence 59 is increased by the electric screw jack 50, the CPU 22 increases the velocity of shaft 18 and test specimen 20 relative to the test surface, so that the test specimen 20 moves across the test surface at a specified velocity with measureable components of vertical and horizontal force required to move the test specimen 20. For example, the test specimen may be moved in the range of 0.25 to 2.0 centimeters per second. Upon establishing a specified velocity, the CPU 22 decreases the test angle 59 at a known rate that corresponds to the amount of movement of the test specimen 20 across the test surface. For example, the test angle may be reduced to one half of its previous amount for each 0.5 to 2.0 centimeters of movement of the test specimen 20. The applied friction is thus increased until a stable velocity is achieved and the measurement of the vertical force required to move the test specimen 20 at a measured test angle 59 yields a dynamic coefficient of friction, which may be stored in memory of the CPU 22.

To determine the dynamic-to-stop stopping coefficient of friction, the axis angle regulation mechanism 24 is controlled by the CPU 22 to decrease test angle 59 while driver 14 move the test specimen 20 across the test surface, resulting in a corresponding increase in the vertical force applied to test specimen 20. The test angle 59 is increased until the CPU 22 measures an instantaneous increase in the forces as the test specimen momentarily stops. The forces measured at the instant of such an increase permit calculation of the dynamic-to-stop stopping coefficient of friction.

The four above-referenced coefficients of friction may thus be measured in a

single data-gathering operation of the testing device 10, which may be termed a complete coefficient of friction "test protocol," or individually in separate data gathering test cycles and test sequences. The forces that form the basis for the calculation of the four coefficients of friction form a continuous curve of information that can be recorded, displayed and processed by the CPU 22. FIG. 15 represents a graph of the typical output of the CPU 22 during a cycle of testing, which represents a profile of the various coefficients of friction under a variety of different testing velocities and surface conditions. This profile may be referred to as a "human coefficient of friction." Referring to FIG. 15, a display of the data collected in four cycles of the testing device 10 is provided. A given test surface may be characterized as being in a given environmental condition, the environmental condition being defined by the state of certain characteristics of the test surface, e.g., degree of cleanliness, contamination with water, oil, or other contaminents, the degree of inherent tread of the test surface, the nature of any compound applied to the test surface, the relative humidity, temperature, and the time of day. A given test sequence is represented by one of the numbered lines on FIG. 15, with the horizontal axis representing the advance of time as the test cycle proceeds. The lettered scales, A, B, C, and D in FIG. 15 indicate schematically the points at which each of the four coefficients of friction are measured during the cycle. Scale A corresponds to the air-to-stop stopping coefficient of friction. Scale B corresponds to the static coefficient of friction. Scale C corresponds to the dynamic coefficient of friction. Scale D corresponds to the dynamic-to-stop stopping coefficient of friction. By varying the parameters of the basic action cycle of basic test cycle, including the selected approach velocity, and the

amount of applied vertical force, the test device 10 can elicit and record all of the coefficients of friction for a given set of parameters. In addition to varying environmental parameters such as the test surface, moisture level and contamination, other parameters, including the material of the test specimen 20 may be varied. The variation of the test specimen 20 material permits the prediction of the effect of different shoe soles on a floor surface. As parameters are varied, different profiles result, as in the numbered lines of FIG. 15. The entire profile of lines, as exemplified in FIG. 15, represents the "human coefficient of friction™" of the test surface under the given environmental conditions, and yields a "floor safety profile™." Referring to FIG. 15, in the profile, as vertical forces and velocity of the test specimen 20 are varied, in this example, the dynamic and dynamic-to-stop coefficients of friction drop sharply, representing the floor safety profile areas where the safety of the test surface diminishes rapidly, indicating that increased potential for slipping will be present when the pedestrian is moving quicker, is heavier, or is simply applying more downward force while accelerating or turning on the test surface under the given environmental conditions. The mere act of a person changing his focus of attention (e.g., reacting to a sound or sight) can cause an instantaneous change in velocity or force for one or more steps even while the pedestrian is in an overall mode of casual walking. In the case of the FIG. 15 profile, such an increase in velocity or force would subject the foot to rapidly decreasing coefficients of friction both in the dynamic and dynamic-to-stop coefficients of friction, indicating that if a slip began that it would be very difficult to arrest.

With the example safety profile of the human coefficient of friction, it is possible for the management to take remedial action in terms of: floor maintenance, floor treatment, increased surface tread or surface treatment, or use of alternative floor surfaces.

The air-to-stop stopping coefficient of friction may alternatively be measured in a separate test cycle. The testing device 10 is positioned on the test surface with a pre-specified, non-zero test angle 59. The CPU 22 directs the ball screw motor 15 to move the shaft 18 toward the test surface at a speed approximating the movement of a foot toward a test surface in the human gait. Referring to FIG. 11, FIG. 12, FIG. 13 and FIG. 14, the CPU 22 measures the vertical and horizontal forces as the test specimen 20 contacts the test surface. If the test specimen 20 slips upon contacting the test surface, then the forces are measured by the CPU 22, the test angle 59 is diminished, and the test cycle is repeated. The test is conducted at different initial test angles 59 until a spike is evident in the forces required to stop the test specimen 20. The coefficient of friction immediately prior the spike in the forces is relevant to the slipperiness of the test surface under the human gait.

The CPU 22 can control the operation of the various components of the testing device 10 to take the testing device 10 through a series of sampling runs where the test specimen 20 materials and/or the force, acceleration, and velocity of the test specimen 20 are varied. The static and dynamic coefficients of friction are then calculated according to their conventional formulas, the dynamic-to-stop stopping coefficient of

friction and the air-to-stop stopping coefficent of friction are calculated as described above, and all four are stored in the CPU 22. The CPU 22 permits a graphical display of the coefficients of friction at each point in the human gait, offering a much more meaningful profile of the slip resistance of a surface than do conventional tribometers.

Referring to FIG. 2, operation of the testing device 10 may further include use of the spraying assembly 32. The reservoirs may be filled with selected contaminants, such as water or soap, of the type that are expected to contact a floor surface. The user may, either manuaily, or through the CPU 22, cause the pump 58 to pump a precisely measured amount of one or more contaminants onto the test surface, thus permitting testing under controlled environmental conditions.

Referring to Fig. 18, the steps by which the CPU 22 uses the application program 136 to operate the testing device may be understood by reference to a flow chart 152. Referring to the flow chart 152, at a first step 154 the user is instructed by the application program 136 to input test parameters. The user is prompted via the graphical user interface 142 to input whether the user wishes to use the computer in manual mode at a step 158. If the user wishes manual control, the user indicates so via the graphical user interface 142 at a step 160 and the angles and forces of the testing device will be controlled by manual means at a step 160. If the user is in manual mode, then the computer control of the flow chart 152 is not desired.

If the user wishes computer-control mode, then, using the graphical user interface

142, the user may indicate use of computer-control mode at a step 162. It should be understood that all data input described herein may be by the graphical user interface of the CPU 22, or by data input via the remote computer 129. The user is next prompted to define a test for the testing device at a step 164. The user is prompted at step 168 to select a basic action cycle for the device. The basic action cycle essentially is a series of physical movements of the test specimen 20 that is controlled by the driver 14 and the adjustment assembly 24. Each basic action cycle consists of the movements necessary to accomplish measurement of a particular coefficient of friction. The basic action cycle takes the driver 14 and the adjustment assembly 24 through a series of pre-defined steps depending on which type of coefficient of friction is to be measured. The type of basic action cycle is selected in step 180 of the flow chart 178, which is connected to the flow chart 152 by off-page connection A.

If the user does not wish to select a particular basic action cycle, or if the user has completed a first basic action cycle, then the user may wish to change variables for a given type of basic action cycle in a step 170 of the flow chart 152 of FIG. 18. This step is referred to as a "test sequence." By repeated returns to the step 170, the user may add to a test sequence, so that a particular basic action cycle is repeated, with any number of different parameters changed. Thus, a test sequence may provide for changes in forces, velocities, and other variables for a given measurement of a given coefficient of friction through the basic action cycle of the step 168 and the flow chart 178. The steps for adding to a test sequence are described in a flow chart 222 that is connected to the flow chart 152 by off-page connector B.

If the user does not wish to further add to the test sequence by varying a particular basic action cycle's parameters, then the user may at a step 172 add to an overall "test protocol". A test protocol refers to measurement of a test surface by the testing device 10 through measurement of a variety of different types of coefficients of friction. That is, a test protocol is built by choosing a number of different types of coefficients of friction in the basic action cycle at the step 168, and by varying parameters for each basic action cycle in one or more test sequences.. Thus, to add to the test protocol at the step 172 the user returns to the step 168 and to the off-page connector A, where the user selects a new type of basic action test cycle at a step 180. Once the user has carried out all desired basic action cycles and has varied all desired parameters for additional test sequences, the user has created the fully desired test protocol. At this point, the user indicates that at the step 172 of the flow chart 152 that the user does not wish to add to the test protocol, thus completing the entire test of the test device and ending the operation device. All data from the basic action cycles is stored in the data storage, manipulator and retrieval application program 136. Also, the design of a particular basic action cycle, test sequence or entire test protocol can be stored for re-use at a future date.

Off-page connector A connects to a flow chart 178, which provides an indication of the operation of one type of basic action test cycle. First at a step 180 the user selects the type of basic action cycle. The different types of basic action cycle correspond to the different types of coefficients of friction. Thus, at a step 182 the user may select to measure the static coefficient of friction. At a step 184 the user may select to measure the dynamic coefficient of friction. At a step 188 the user may select to measure the air-to-

stop coefficient of friction. At a step 190 the user may elect to measure the dynamic-to-stop coefficient of friction. At a step 192 the user may select to combine different coefficients of friction in a single action cycle. The basic action cycles thus correspond to measurement of different coefficients of friction.

The basic action cycles of the device are controlled through the use of the driver 14 and the adjustment assembly 24. The application program 136 is programmed to carry the device through a pre-described set of motions. As the device travels through these motions, the sensor 127 of the driver 14, the load sensor 250 of the load cell 36, the spraying sensor 123 of the spraying assembly 32, and the adjustment sensor 125 of the adjustment assembly 24 all provide data through the data connection 150 to the CPU 22 for storage in the data storage, manipulation, and retrieval application 140. The flow chart 178 provides an example of a basic action cycle for a particular coefficient of friction, namely, the air-to-stop coefficient of friction. When the user selects the air-to-stop coefficient of friction at the step 188, the user is then prompted to select an initial velocity at a step 194 upon input of the initial velocity through the graphical user interface 142 of the CPU 22. The user is then prompted to select an initial angle for the testing device 10 at a step 198.

Upon initiation of the basic action cycle, the testing device 20 uses the driver 14 to advance the test arm at the selected velocity of a step 200. The sensors described above record all data regarding the operation of the testing device at the step 202. At a step 204 the force that is measured at the step 202 is compared to a predetermined amount of

force, e.g., 10 lbs. If the force exceeds the predetermined amount, then at a step 208 the angle is adjusted by the adjustment assembly 24 and the device is returned to the step 200 to advance the test arm again at the same velocity at the step 200 and to record the data at the step 202. These steps are repeated as long as the force exceeds the predetermined amount at the step 204, but in each case the device is returned with an increasing angle of impact. The angle is increased each time at the step 208 by a predetermined amount.

If the force of the step 204 is less than the predetermined amount, then the application program 136 determines whether the force initially rises and then falls to zero at a step 210. If the force does not initially rise and the fall to zero, then at a step 214 the angle is adjusted, but the adjustment to the angle is smaller than the adjustment to the angle at the step 208 which applies in cases where the force exceeds the predetermined amount. Also, the adjustment is made by first returning to the last angle for which the force was determined to be greater than the predetermined amount at the step 204 and then increasing the angle by the smaller amount.. Once the angle is adjusted by the smaller amount at the step 214, the device returns to the step 200 and advances the test arm at the predetermined velocity and records the data at the step 202. The force is then again measured at the step 204, which depending on the measured force, can result in a return to the step 208 or to the step 210 for further measurement of adjustment.

Repeated adjustments of the angle at the steps 214 and 208 should eventually cause the test specimen 20 to slip on the surface; that is, the force measured should initially rise and then drop to zero. If at the step 210 the force is determined to rise then

fall to zero, then the device is prompted to determine whether the previous advancement of the test arm at the step 200 followed a small adjustment at a step 214 of the angle. If a determination is made at a step 212 that the proceeding test was after a small adjustment of the angle at the step 214, then the application program 136 determines that the air-to-stop coefficient of friction has been determined for this velocity at a step 218. If at the step 212 it is determined that the adjustment prior to the advancement of the test at 200 was a large adjustment (at a step 208), or if this was the first operation of the test arm at the step 200, then the testing device returns to the step 214 for a small adjustment of the angle.

Once at the step 218 the device has determined that the air-to-to stop coefficient of friction is known, all of the data has been delivered to the CPU 22, including all of the forces, velocities and accelerations for each of the operations of the basic action test cycle recorded at the step 202.

Upon completion of a basic action cycle, the user returns to the steps of the flow chart 152 connected by off-page connector A to the flow chart 178 to determine whether the user at the step 170 wishes to add to a test sequence. It should be noted that the flow chart 178 shows the details of the air-to-stop coefficient of friction measurement. However, the measurement of any other type of coefficient of friction would follow a similar set of physical movements of the test device components. The mathematical measurements of the coefficients of friction are described elsewhere herein, and one of ordinary skill in the art would understand that programing of the device to measure these

other coefficients of friction would require steps analogous to those disclosed for measuring the air-to-stop coefficient of friction.

If at the step 170 the user wishes to add to a test sequence, then the user is returned to the step 180 and is prompted to select the same coefficient of friction at the step 180. Upon selecting the same basic action cycle, or coefficient of friction, the user is then again prompted to input the various parameters for the test sequence. The input of these parameters to create a test sequence for a given basic action cycle is reflected in the flow chart 222 connected to the flow chart 152 by off-page connector B.

Turning to flow chart 222, the user is first prompted at a step 224 to stay in the same type of basic action cycle. Next, the user is prompted in a series of steps to change one or more of a variety of variables. For example, at a step 228 the user may change the initial velocity for the basic action cycle, in which case the user is prompted at a step 230 to input the new velocity. The user may be prompted whether the user wishes to change the test pad at a step 232. If the user wishes to change the test pad, then the user does so at a step 234. At a step 238 the user is prompted to determine whether the user wishes to change the heel pressure applied by the device. If the answer is affirmative, then at a step 240 the user adjusts the torque of the clutch 120 to provide additional pressure on the test surface while the testing device 10 is not in motion. If the user wishes to change the surface at a step 242, then the user indicates so and the user may at a step 244 spray or otherwise contaminate the surface.

One can envision many parameter variations for a given basic action cycle. It may be noted that certain steps in the flow chart 222 are applicable only for certain types of basic action cycle. Thus, for example, the change of heel pressure at the step 238 is not applicable to the air-to-stop co-efficient of friction in the basic action cycle of the flow chart 178, because the test specimen 20 is not stopped during that cycle except at the end of the cycle. Different parameters may be needed for measurement of different basic action cycles. By varying the parameters in the test sequence of the flow chart 222, the user may initiate any number of basic action cycles with different variables. The collection of these basic action cycles with different perimeters results in a complete test sequence.

Once a test sequence is complete; that is, once the user does not wish to vary any additional parameters at the step 170, the user is prompted to determine whether user wishes to add to the overall test protocol at the step 172 of the flow chart 152. If so, at the step 172, the user is returned to the basic action cycle 168 and is prompted to select a different type of basic action cycle, which, by repeated operation, results in carrying out a series of test sequences in which the parameters for different coefficients of friction are varied.

At each of the basic action cycle steps data is provided to the CPU 220. Thus, through a series of basic action cycles, test sequences and test protocols the user is able to provide data to the data storage, manipulation, and retrieval application 140, creating an entire history of coefficient of friction measurements that are output during operation of the testing device 10.

While the invention has been disclosed in connection with the preferred embodiments shown and described in detail, various modifications and improvements thereon will become readily apparent to those skilled in the art. Accordingly, the spirit and scope of the present invention is to be limited only by the claims.

What is claimed is:

1. An apparatus for measuring a coefficient of friction of a surface, comprising:

a central processing unit;

a frame;

a driver, disposed on the housing and responsive to the central processing unit;

a shaft, disposed on the housing and responsive to the driver; and

a test assembly, disposed on the shaft, the test assembly including at least a test specimen.

2. The apparatus of claim 1, wherein the driver is an electronic screw drive.

3. The apparatus of claim 2, wherein the screw drive is driven by an electronically controlled motor.

4. The apparatus of claim 3, wherein the shaft is moveable in a linear direction and an angular direction relative to the frame.

5. The apparatus of claim 4, wherein the test assembly further comprises a load cell and wherein the driver and the load cell are responsive to and in data connection with the central processing unit.

6. The apparatus of claim 5, further comprising an adjustment assembly for adjusting the angular position of the shaft, the adjustment assembly responsive to and in data

connection with the central processing unit.

7. The apparatus of claim 6, wherein the adjustment assembly comprises an electronic screw drive.

8. The apparatus of claim 8, wherein the test assembly further comprises a sensor pad base, for attachment of the test specimen, and a compressible link, disposed between the load cell and the sensor pad base.

9. The apparatus of claim 9, wherein the compressibility of the compressible link may be adjusted by the user.

10. The apparatus of claim 10, wherein the compressible link is controlled by o[illegible] in data connection with the central processing unit.

11. The apparatus of claim 7, further comprising a spraying assembly, the spraying assembly in responsive to and in data connection with the central processing unit.

12. The apparatus of claim 8, further comprising an application program, the application program capable of controlling at least one of the driver, the adjustment assembly, the spraying assembly, and the compressible link.

13. The apparatus of claim 9, further comprising a database program, the database

program capable of storing, manipulating and retrieving data from at least one of the application program, the driver, the adjustment assembly, the test assembly, the spraying assembly and the compressible link.

14. The apparatus of claim 13, wherein the compressible link is a fluid filled bag.

15. The apparatus of claim 13, wherein the compressible link includes opposing magnetic components.

16. The apparatus of claim 13, wherein the driver further comprises a clutch for adjustment of the amount of torque applied by the motor.

17. An apparatus for measuring a coefficient of friction of a surface, comprising:

a central processing unit;

a frame;

a driver, disposed on the frame, the driver responsive to and in data connection with the central processing unit;

a shaft, disposed on the frame and responsive to the driver, wherein the shaft is moveable in a linear direction and an angular direction relative to the frame;

a test assembly, disposed on the shaft, the test assembly including at least a test specimen;

a load cell, responsive to and in data connection with the central processing unit;

an adjustment assembly for adjusting the angular position of the shaft, the

adjustment assembly responsive to and in data connection with the central processing unit, the adjustment assembly comprising an electronic screw drive; and

a spraying assembly, the spraying assembly in responsive to and in data connection with the central processing unit.

18. The apparatus of claim 17, wherein the driver further comprises:

an electronic ball screw assembly, and

a clutch for adjustment of the amount of torque applied by the motor.

19. The apparatus of claim 17, wherein the test assembly further comprises a compressible link, the compressibility of the compressible link responsive to the central processing unit.

20. The apparatus of claim 17, wherein the driver comprises a robotic arm.

21. A testing device, for measuring a coefficient of friction, comprising:

a central processing unit;

a frame;

a driver, disposed on the housing, the driver responsive to in data connection with the central processing unit;

a shaft, disposed on the housing and responsive to the driver, the shaft movable in a linear and an angular direction;

an adjustment assembly, responsive to and in data connection with the central

processing unit, for adjustment of the shaft in a linear and an angular direction; and

a test assembly, disposed on the shaft, the test assembly including at least a test specimen, the test assembly in data connection with the central processing unit, the test assembly capable of measuring the force, velocity and acceleration of the test specimen on a surface;

an application program, for control of at least one of the driver and the adjustment assembly; and

a database program, for storage, manipulation and retrieval of data from at least one of the driver, the adjustment assembly and the test assembly.

22. The testing device of claim 21, further comprising:

a spraying assembly, the spraying assembly responsive to and in data connection with the central processing unit, wherein the application program controls the spraying assembly and the database program stores, manipulates or retrieves data from the spraying assembly.

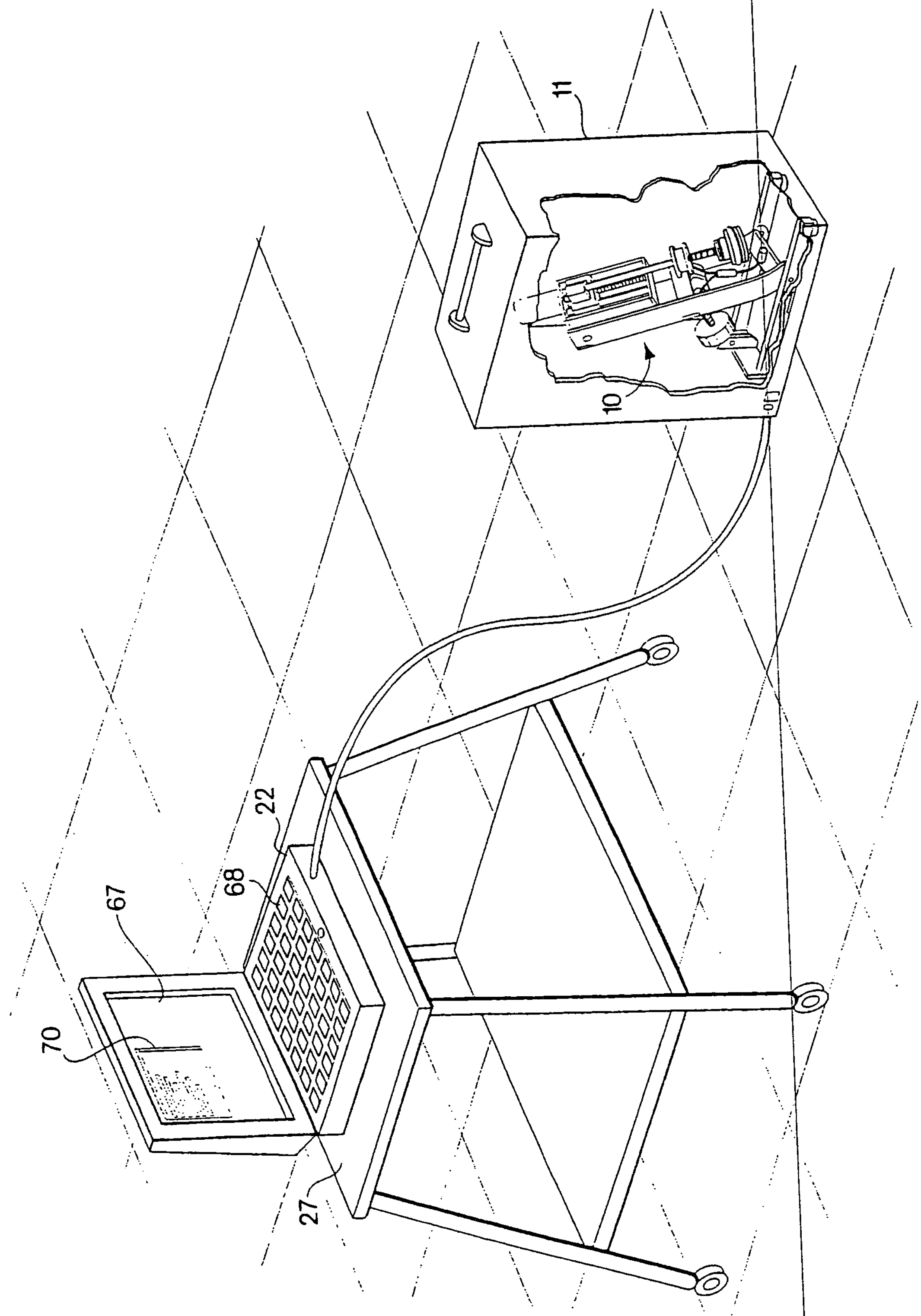

Fig. 1

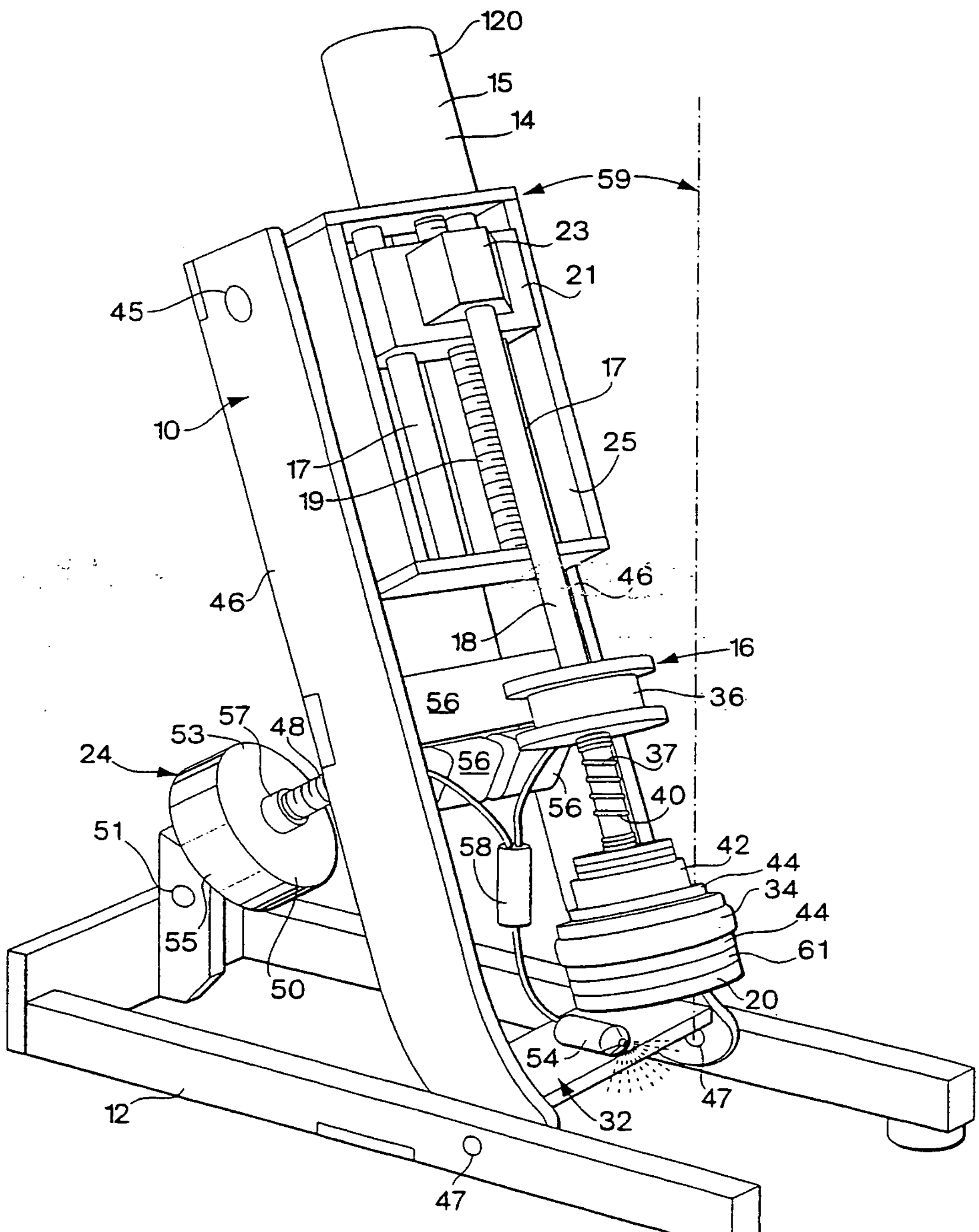
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Fig. 2

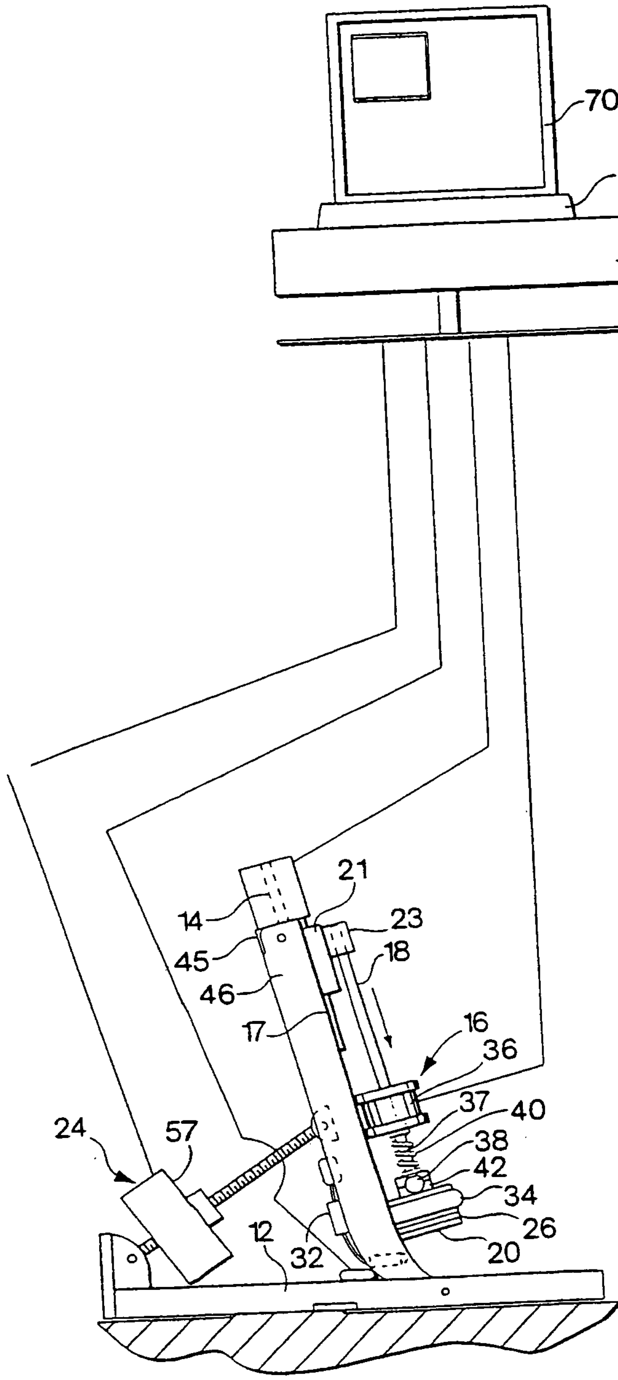

Fig. 3

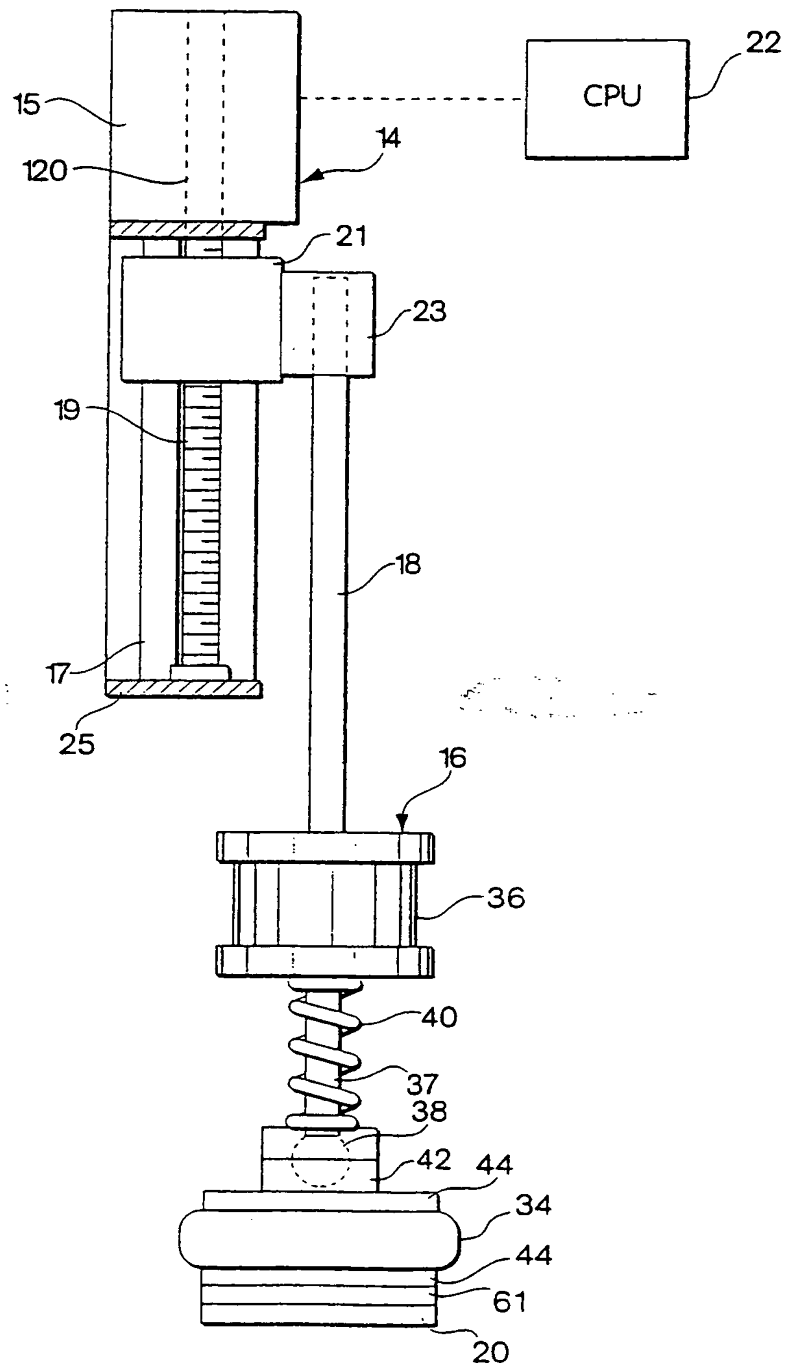

Fig. 4

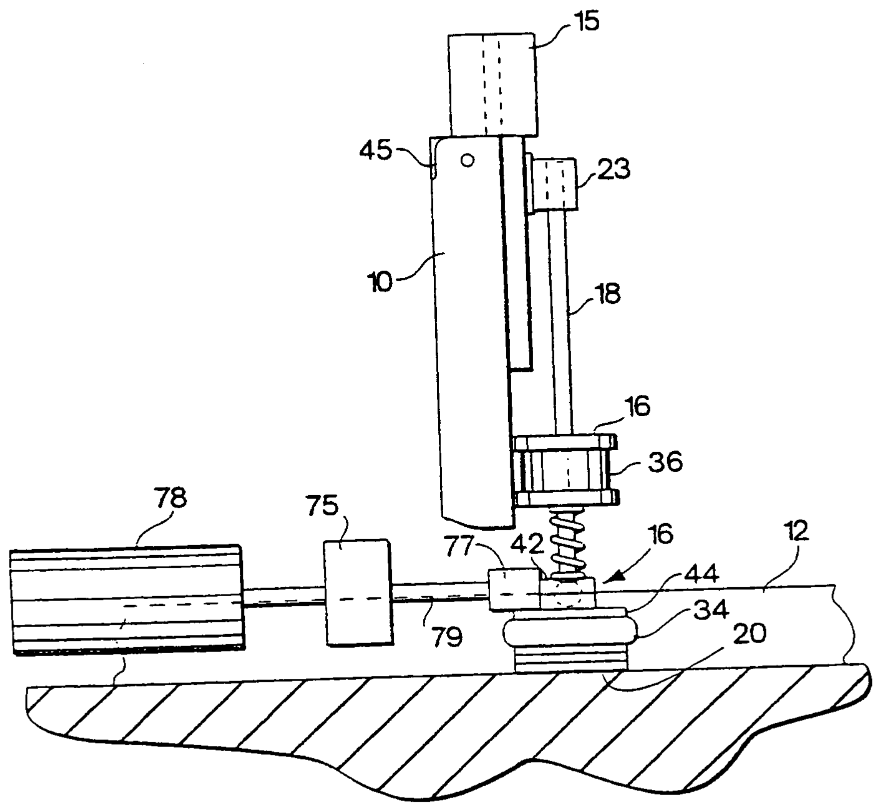
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Fig. 5

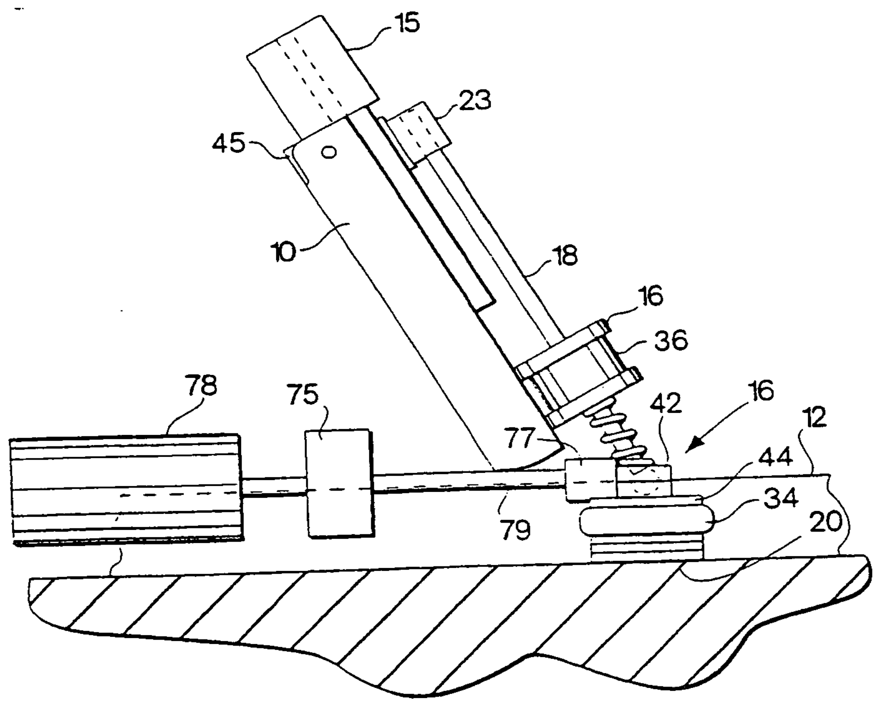
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Fig. 6

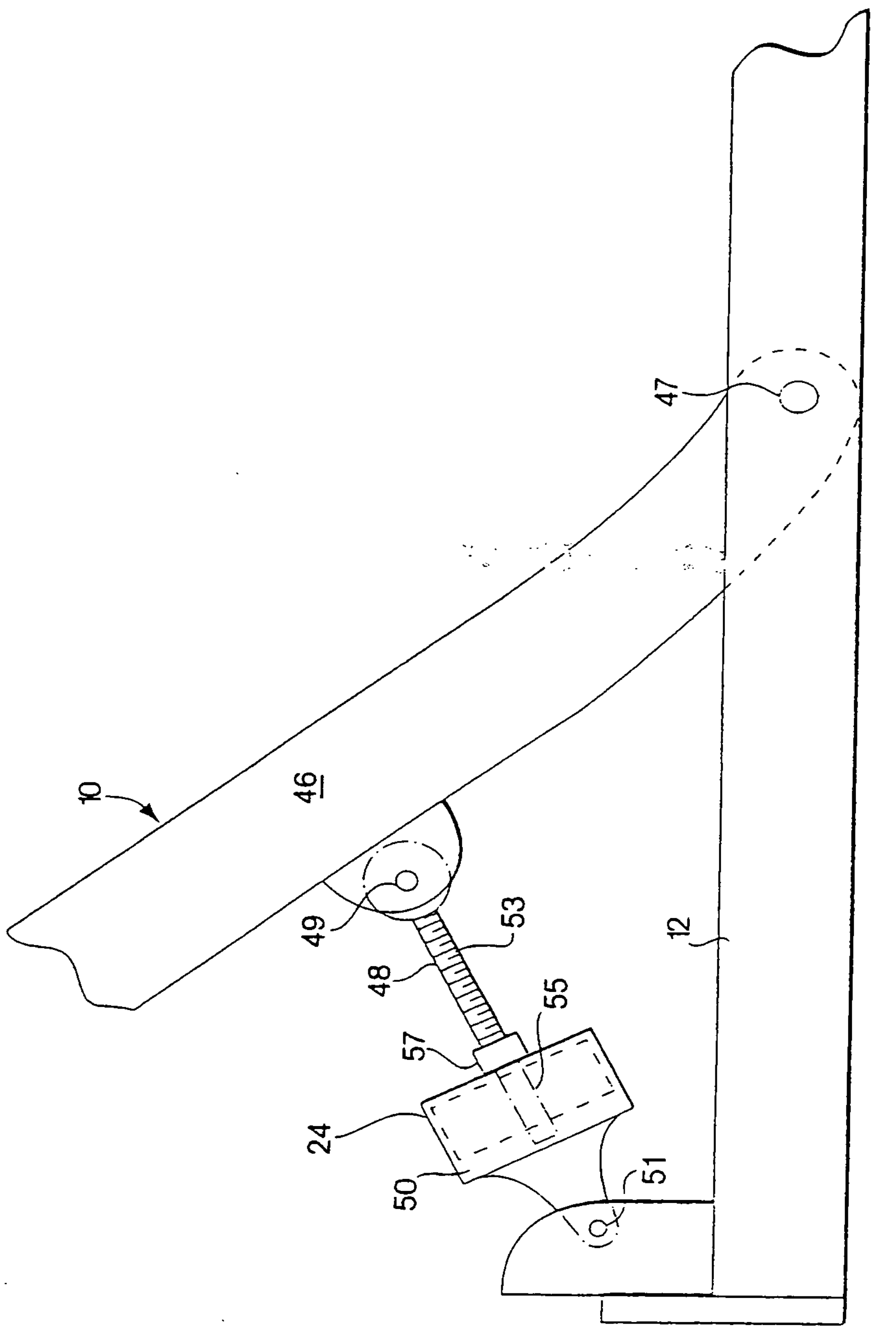

Fig. 7

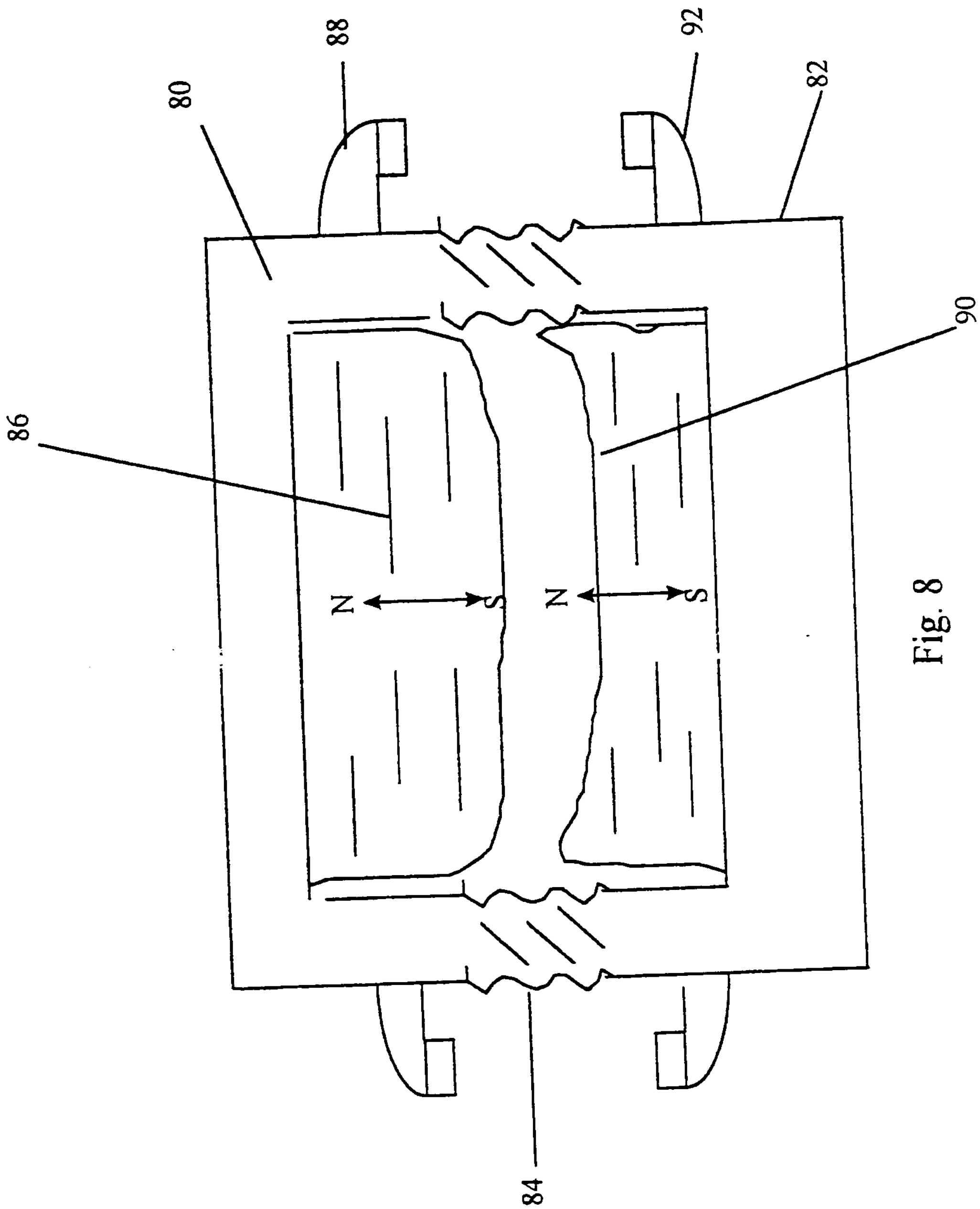

Fig. 8

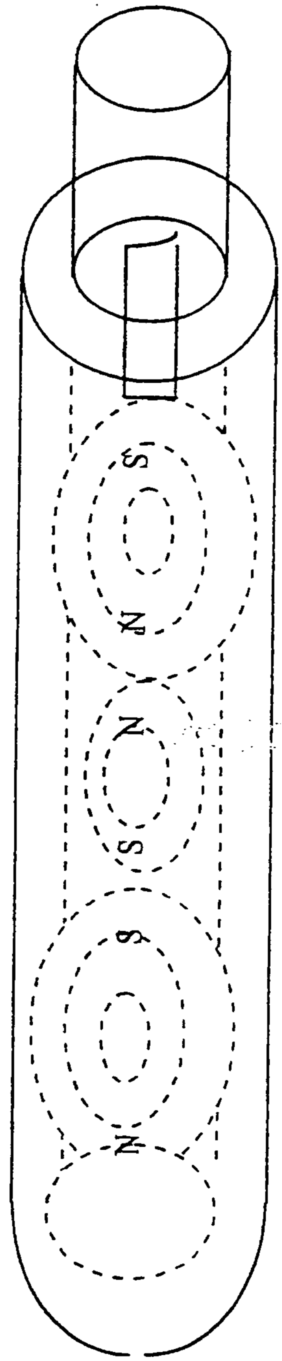

Fig. 9

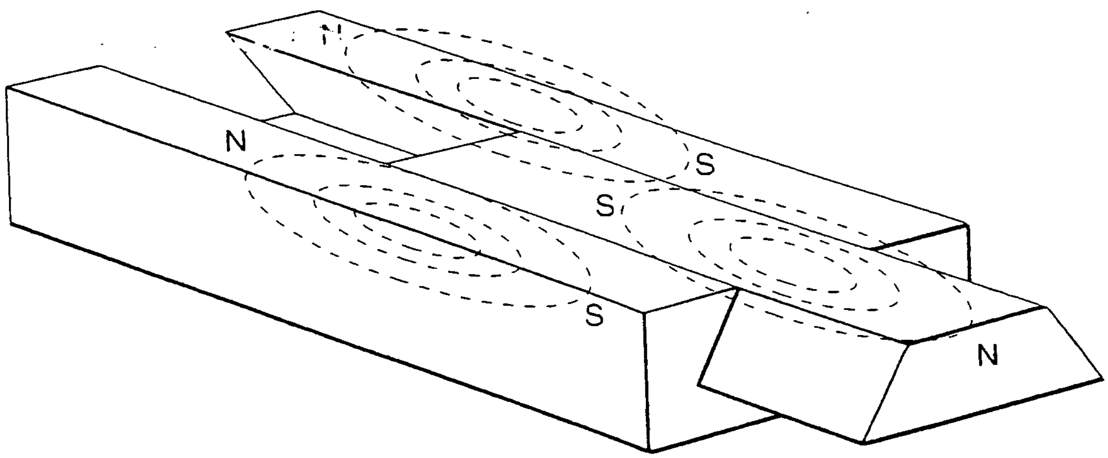

Fig. 10

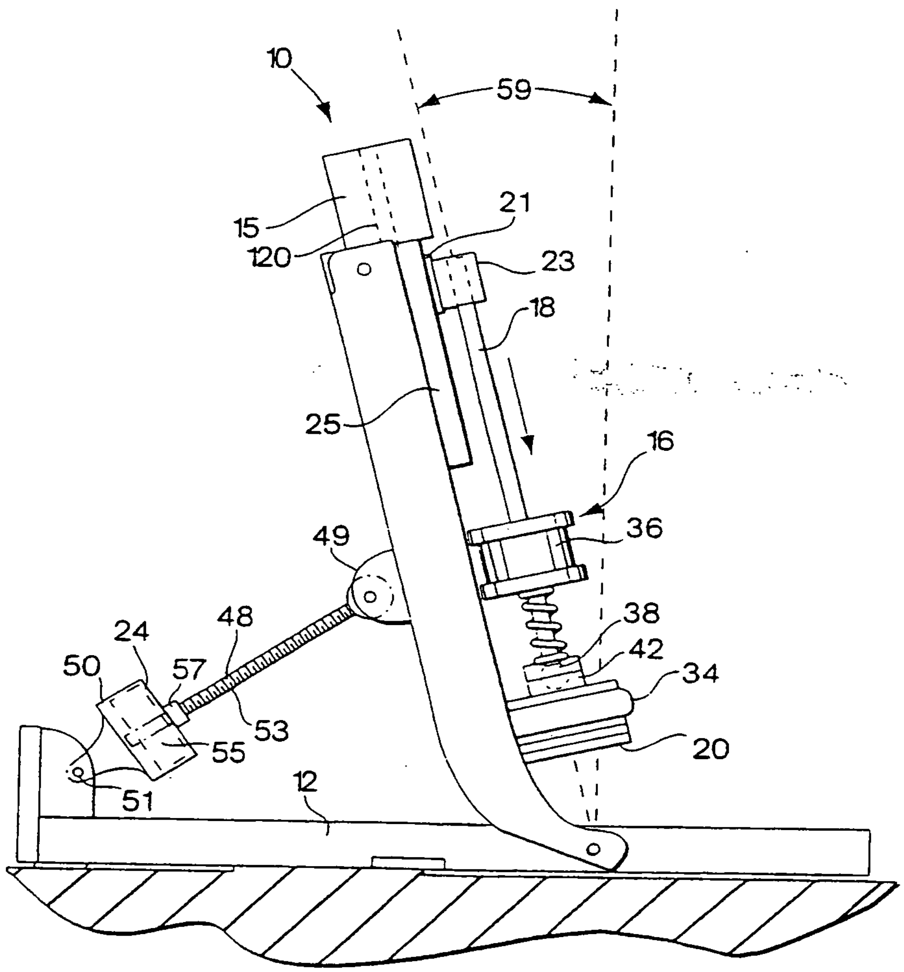

Fig. 11

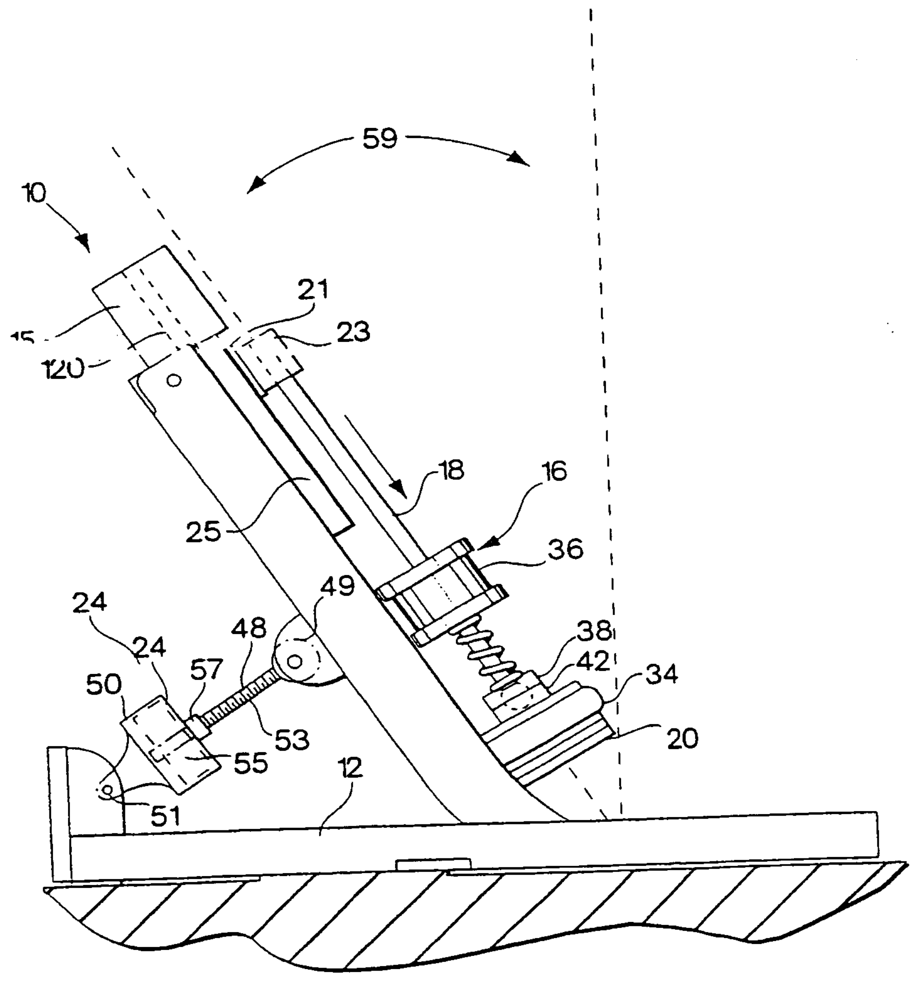

Fig. 12

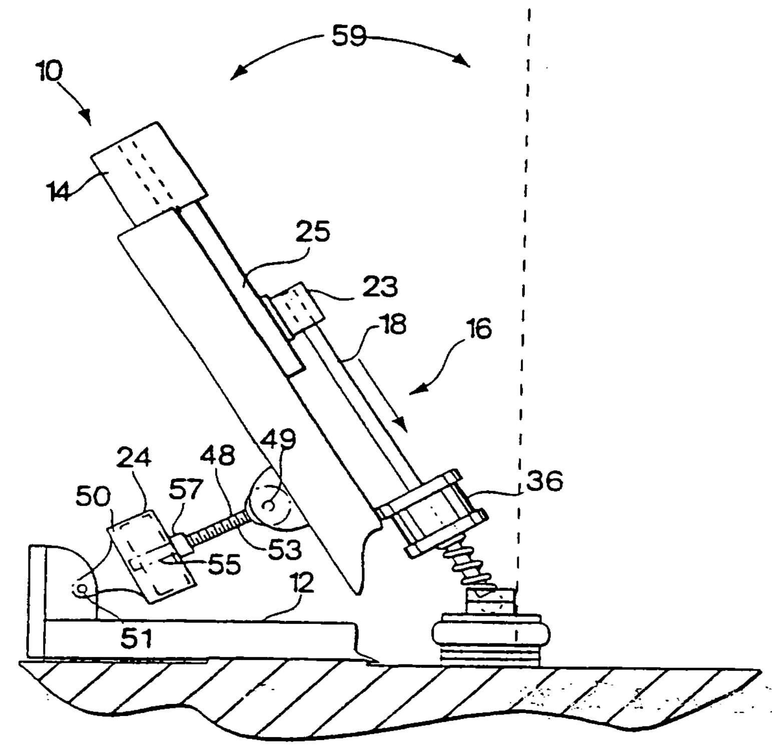
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Fig. 13

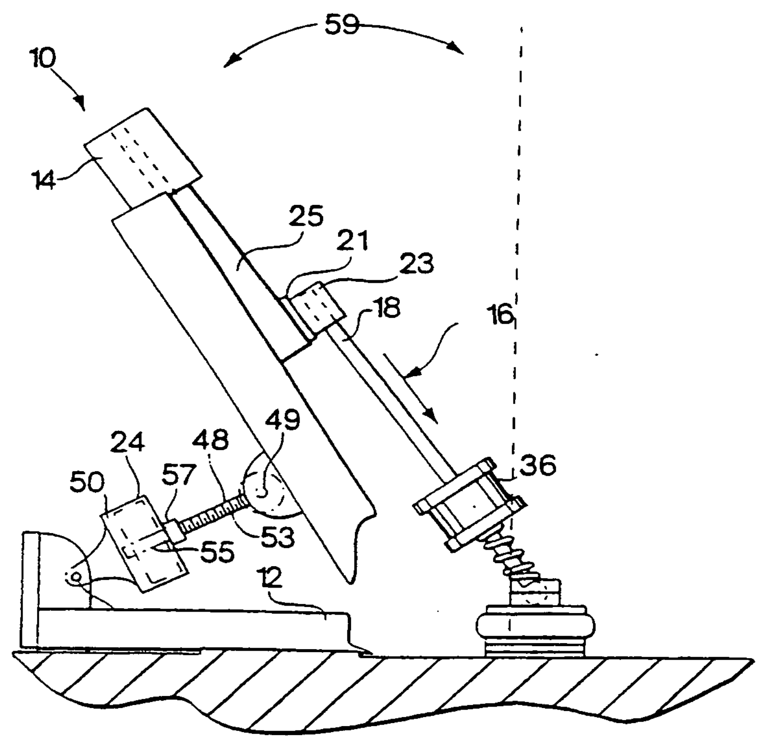
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Fig. 14

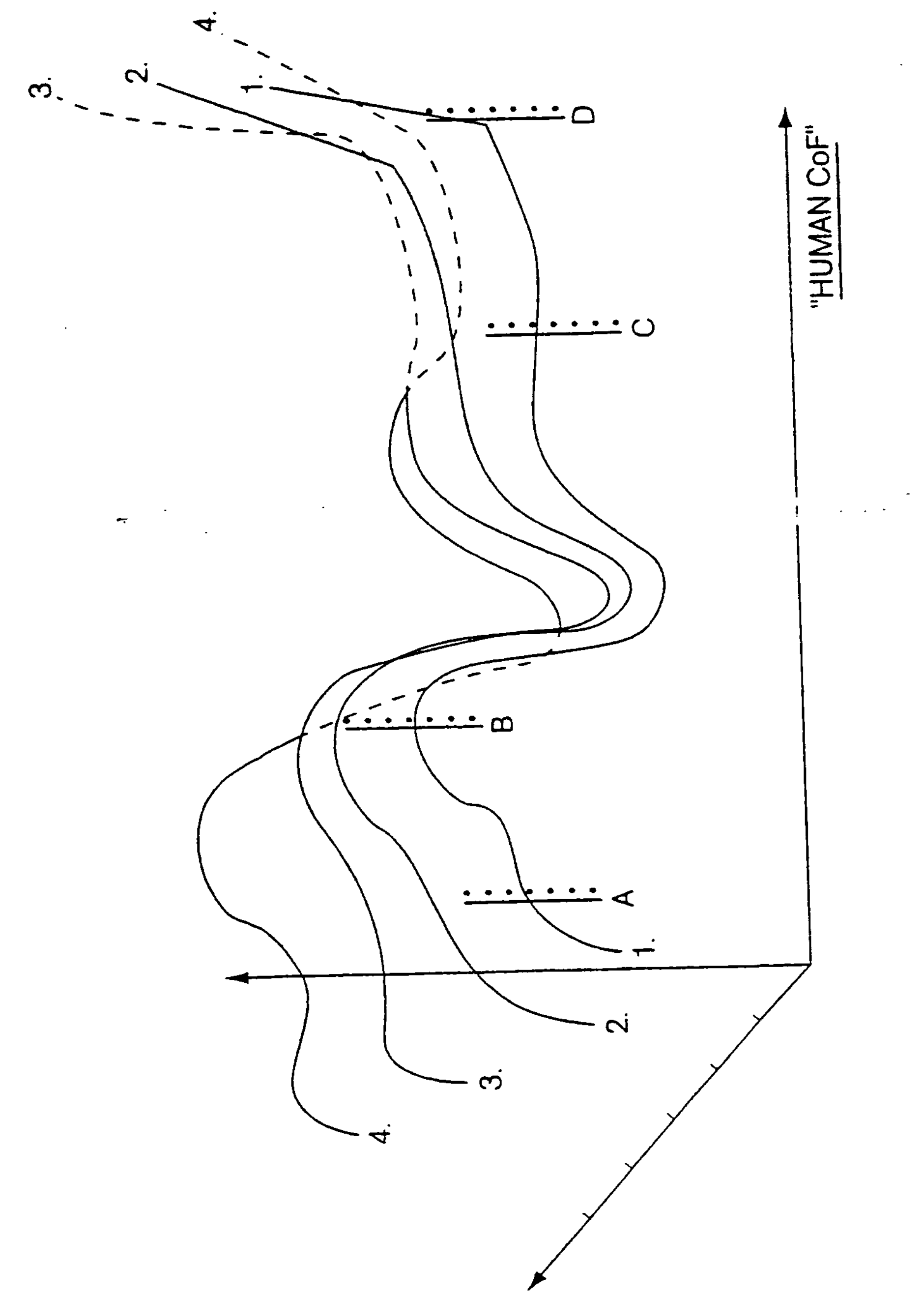

Fig. 15

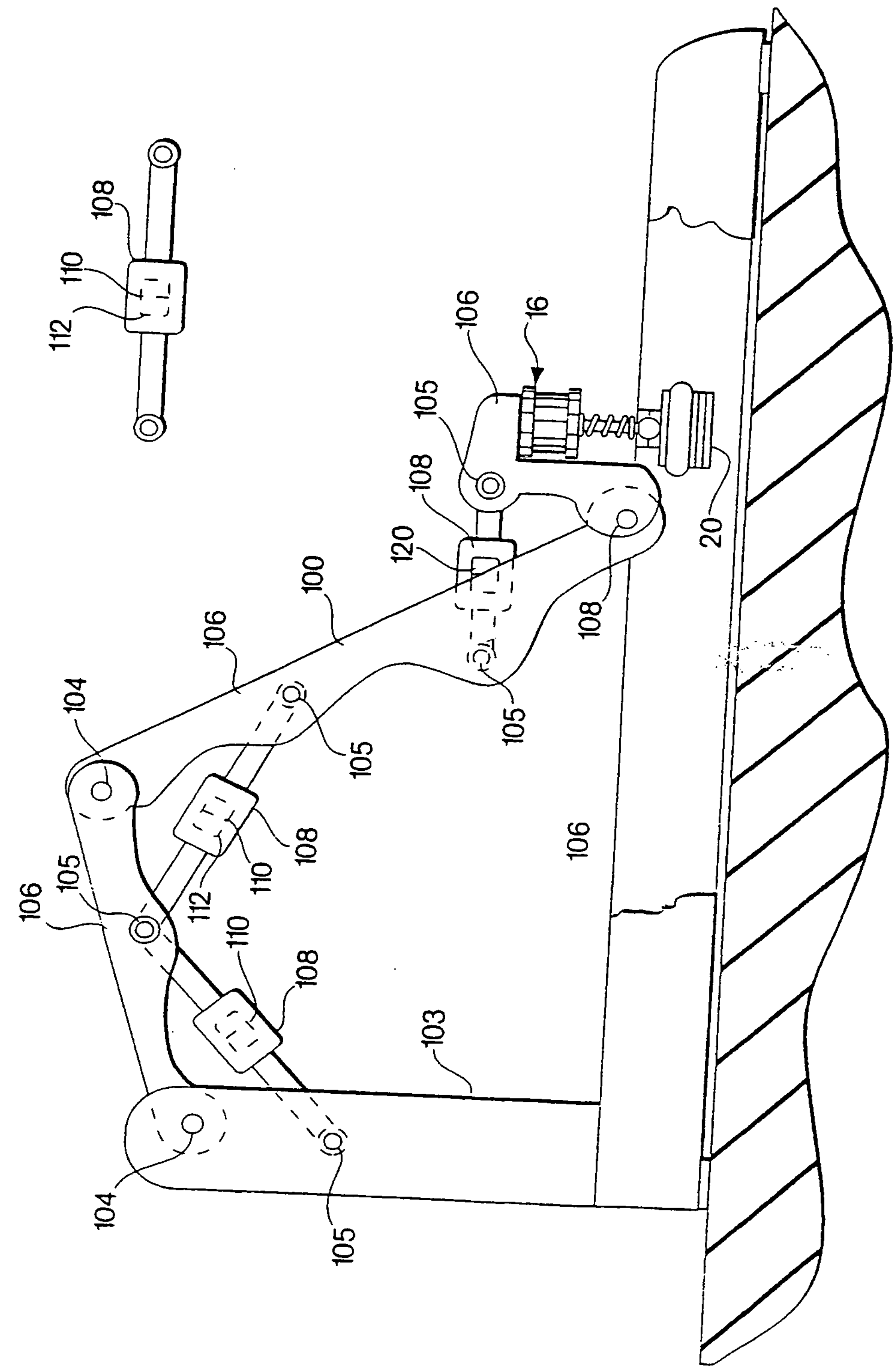
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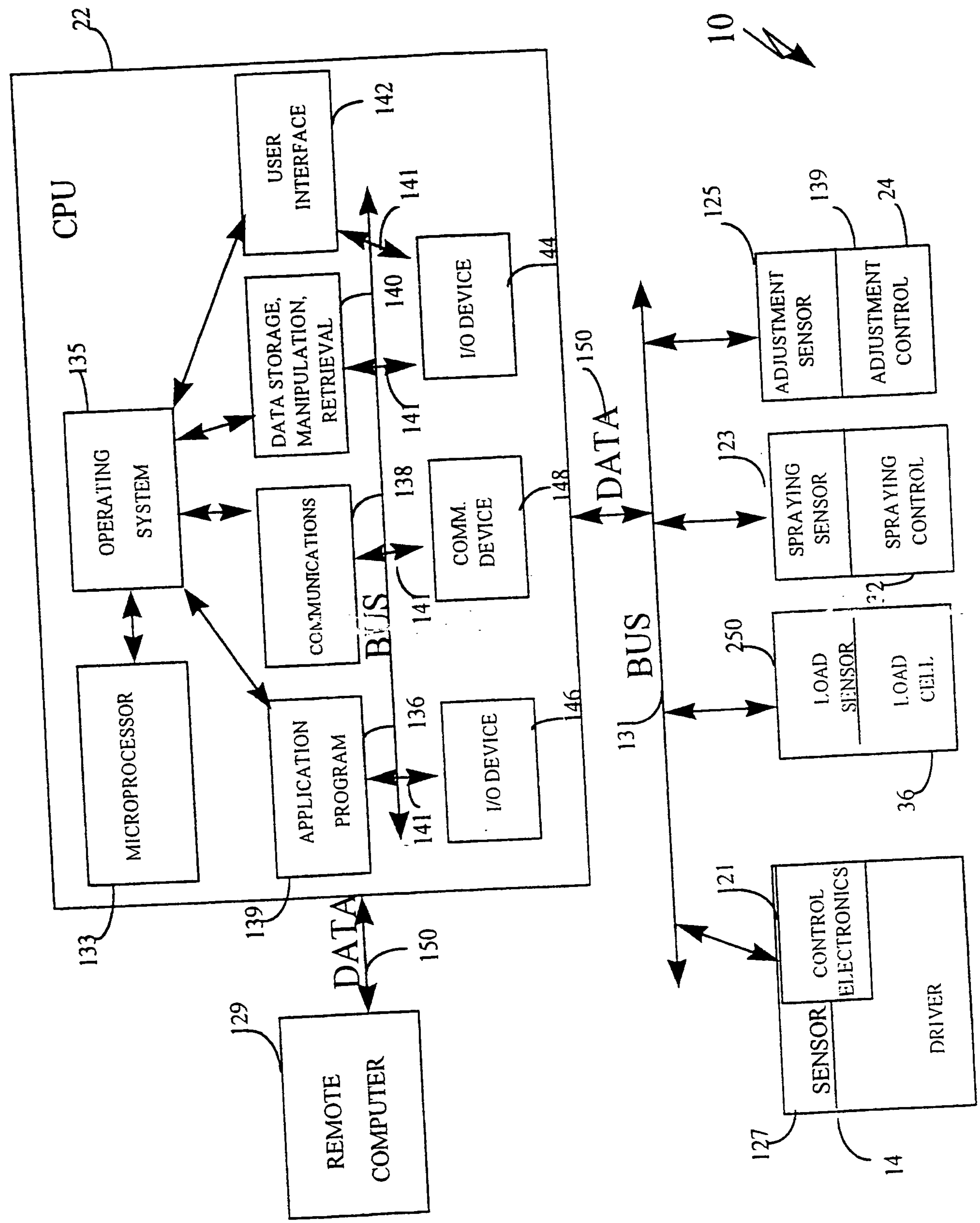
Fig. 16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USER INTERFACE
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DATA STORAGE, MANIPULATION, RETRIEVAL
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I/O DEVICE
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OPERATING SYSTEM
141
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COMMUNICATIONS
138
COMM. DEVICE
148
DATA
BUS
141
MICROPROCESSOR
APPLICATION PROGRAM
136
I/O DEVICE
146
141
BUS
131
133
139
DATA
150
129
REMOTE COMPUTER
125
139
24
ADJUSTMENT SENSOR
ADJUSTMENT CONTROL
123
SPRAYING SENSOR
SPRAYING CONTROL
22
250
LOAD SENSOR
LOAD CELL
36
121
CONTROL ELECTRONICS
SENSOR
DRIVER
127
14

Fig. 17

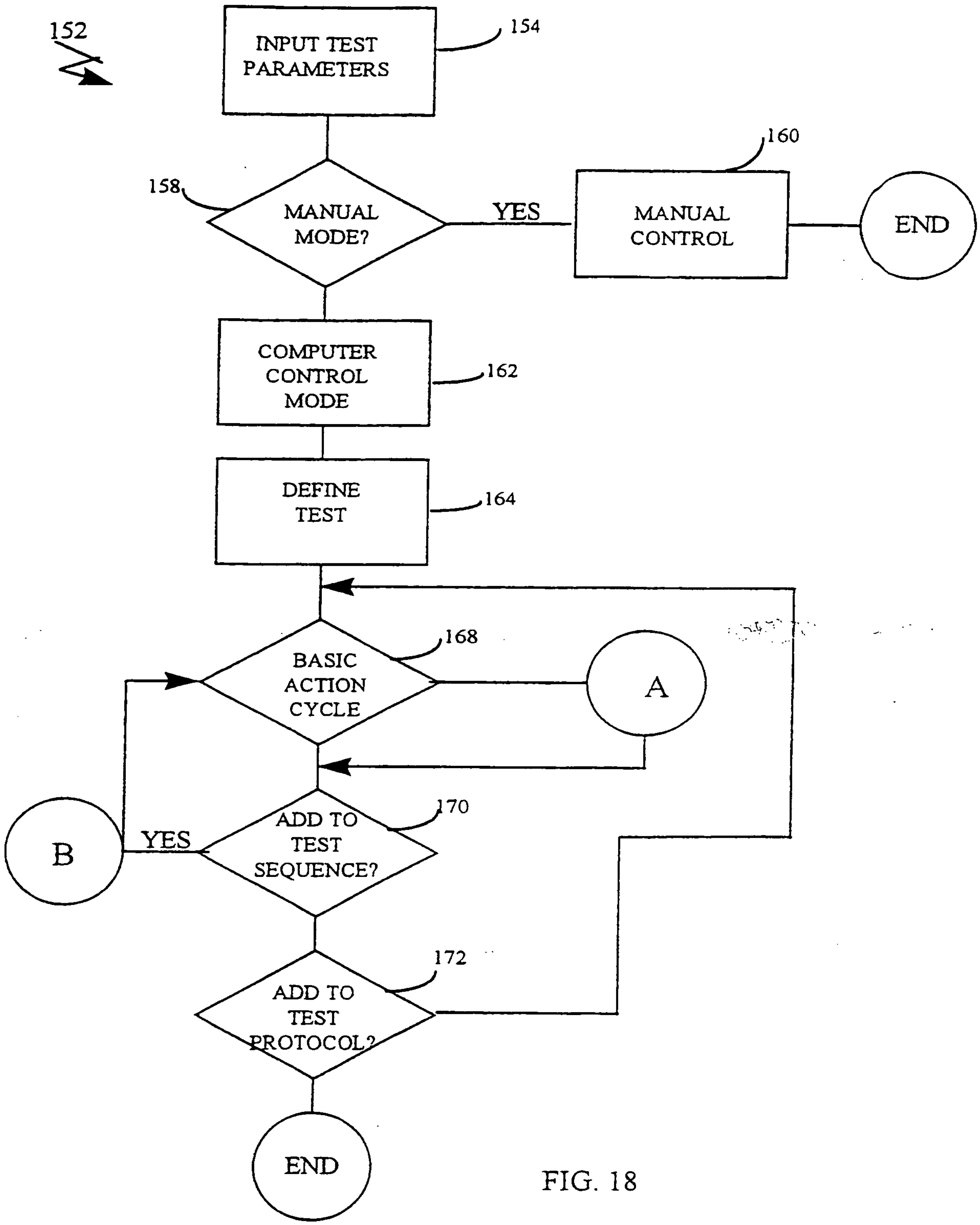
152
INPUT TEST PARAMETERS
154
158
MANUAL MODE?
YES
160
MANUAL CONTROL
END
COMPUTER CONTROL MODE
162
DEFINE TEST
164
168
BASIC ACTION CYCLE
A
170
B
YES
ADD TO TEST SEQUENCE?
172
ADD TO TEST PROTOCOL?
END

FIG. 18

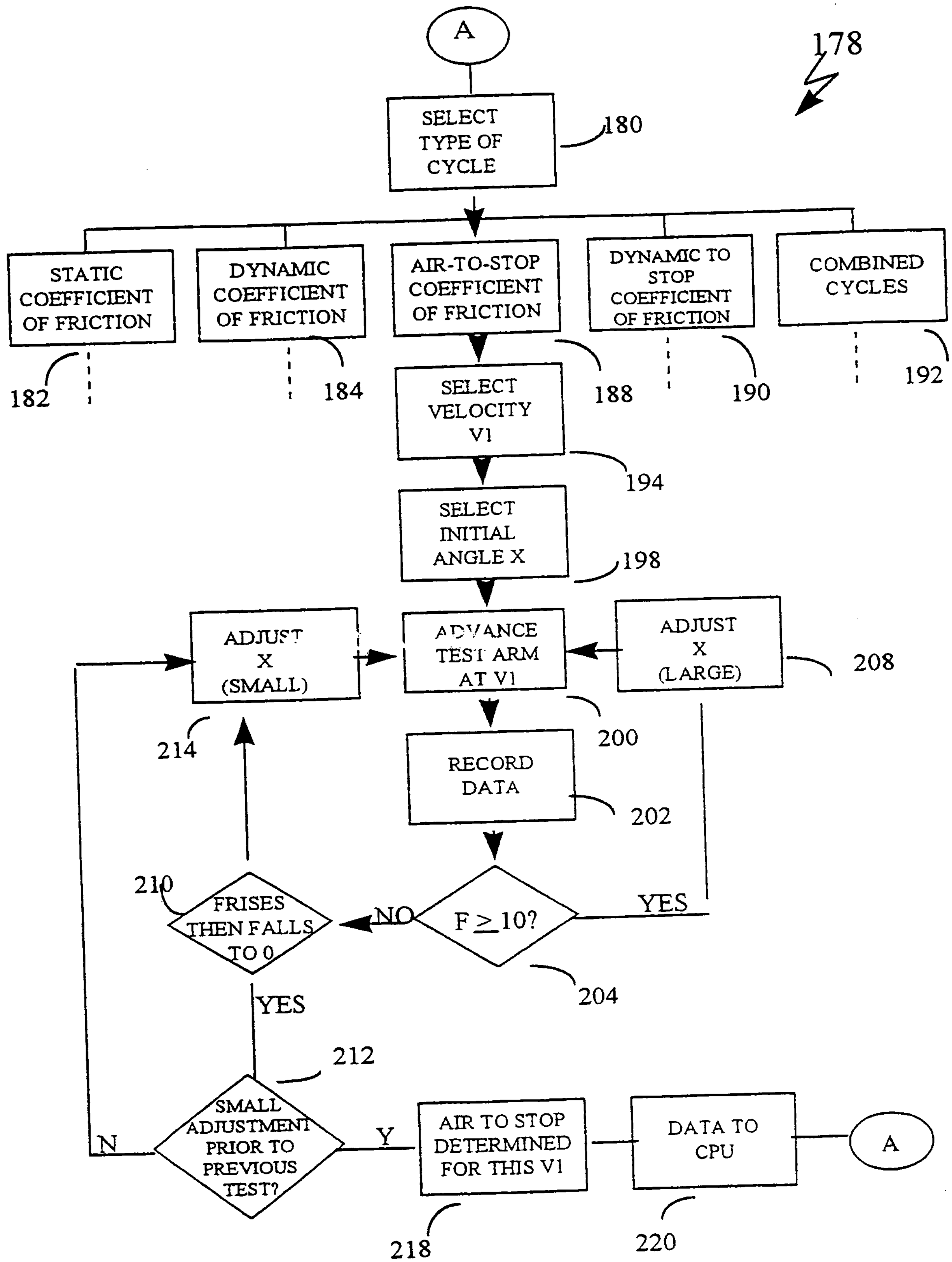
A
178
SELECT TYPE OF CYCLE
180
STATIC COEFFICIENT OF FRICTION
DYNAMIC COEFFICIENT OF FRICTION
AIR-TO-STOP COEFFICIENT OF FRICTION
DYNAMIC TO STOP COEFFICIENT OF FRICTION
COMBINED CYCLES
182
184
188
190
192
SELECT VELOCITY V1
194
SELECT INITIAL ANGLE X
198
ADJUST X (SMALL)
ADVANCE TEST ARM AT V1
ADJUST X (LARGE)
208
200
214
RECORD DATA
202
210
FRISES THEN FALLS TO 0
NO
F ≥ 10?
YES
204
YES
212
SMALL ADJUSTMENT PRIOR TO PREVIOUS TEST?
N
Y
AIR TO STOP DETERMINED FOR THIS V1
DATA TO CPU
A
218
220

FIG. 19

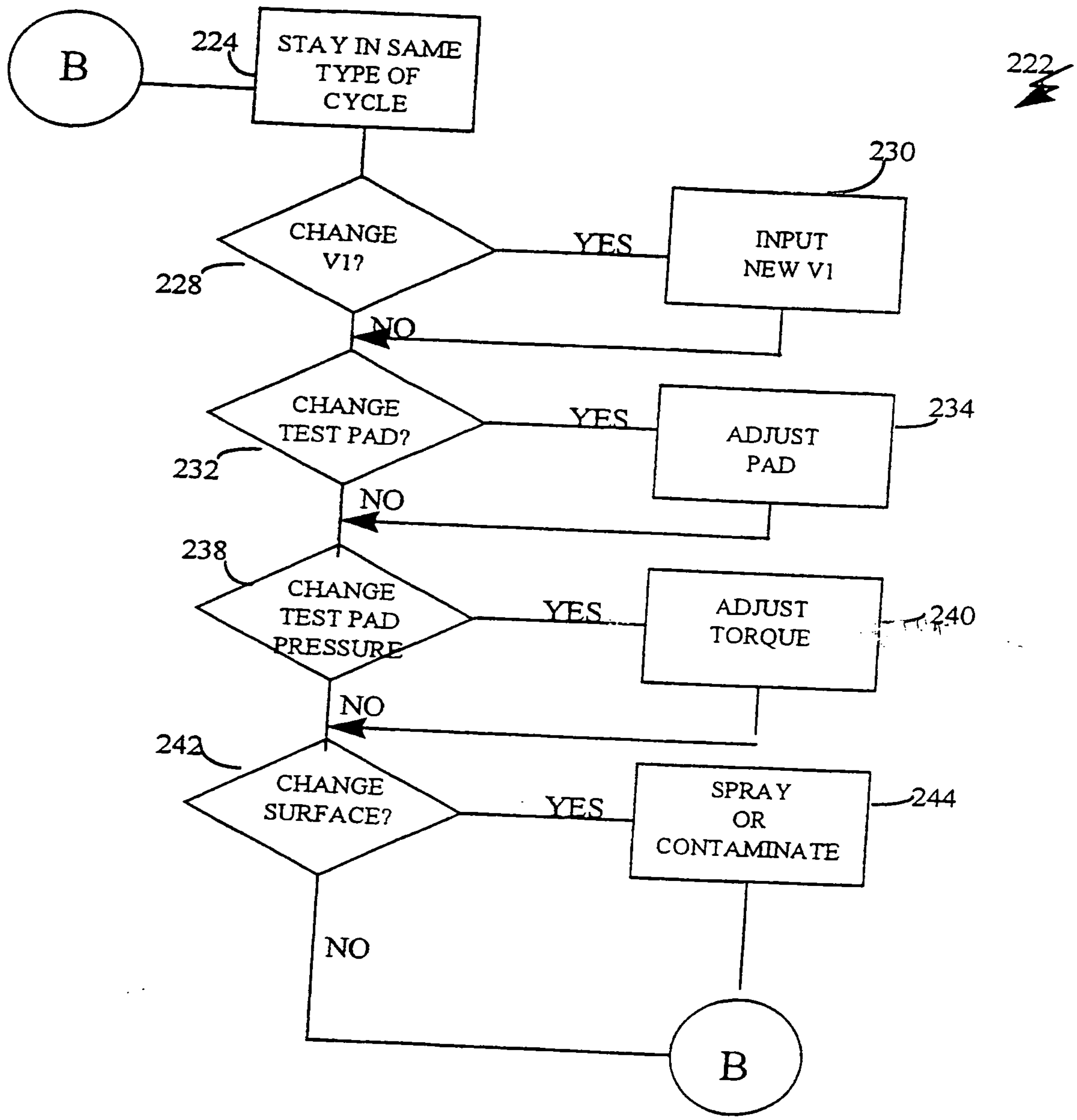
B
224
STAY IN SAME TYPE OF CYCLE
222
230
CHANGE V1?
YES
INPUT NEW V1
228
NO
CHANGE TEST PAD?
YES
ADJUST PAD
234
232
NO
238
CHANGE TEST PAD PRESSURE
YES
ADJUST TORQUE
240
NO
242
CHANGE SURFACE?
YES
SPRAY OR CONTAMINATE
244
NO
B

FIG. 20

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/02617

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :G01N 19/02
US CL : 73/9
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/9,10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	US 5,259,236 A (ENGLISH) 09 November 1993 (09/11/93) abstract and Figs. 2,3, 7-11, 13 and 14	1-7 and 21 --- 17
Y --- A	US 4,662,211 A (STRONG) 05 May 1987 (05/05/87) Abstract and Figs. 1, 4, 5A, and 5B	1-7 and 21 --- 17

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 14 MAY 1998	Date of mailing of the international search report 08 JUL 1998
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer TOM NOLAND Telephone No. (703) 305-4765

Form PCT/ISA/210 (second sheet)(July 1992)*

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

APS: files USPAT, USOCR, JPOABS, EPOABS
search terms: test?, measur?, coefficient?, friction?, fram?, driv?, cpu#, comput?, minicomput?, microcomput?, microprocess?, micro, central?, process!r#,processing#, housing#,shaft?,sample#, specimen#

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